O I P E
FEB 05 2004
PATENT & TRADEMARK OFFICE

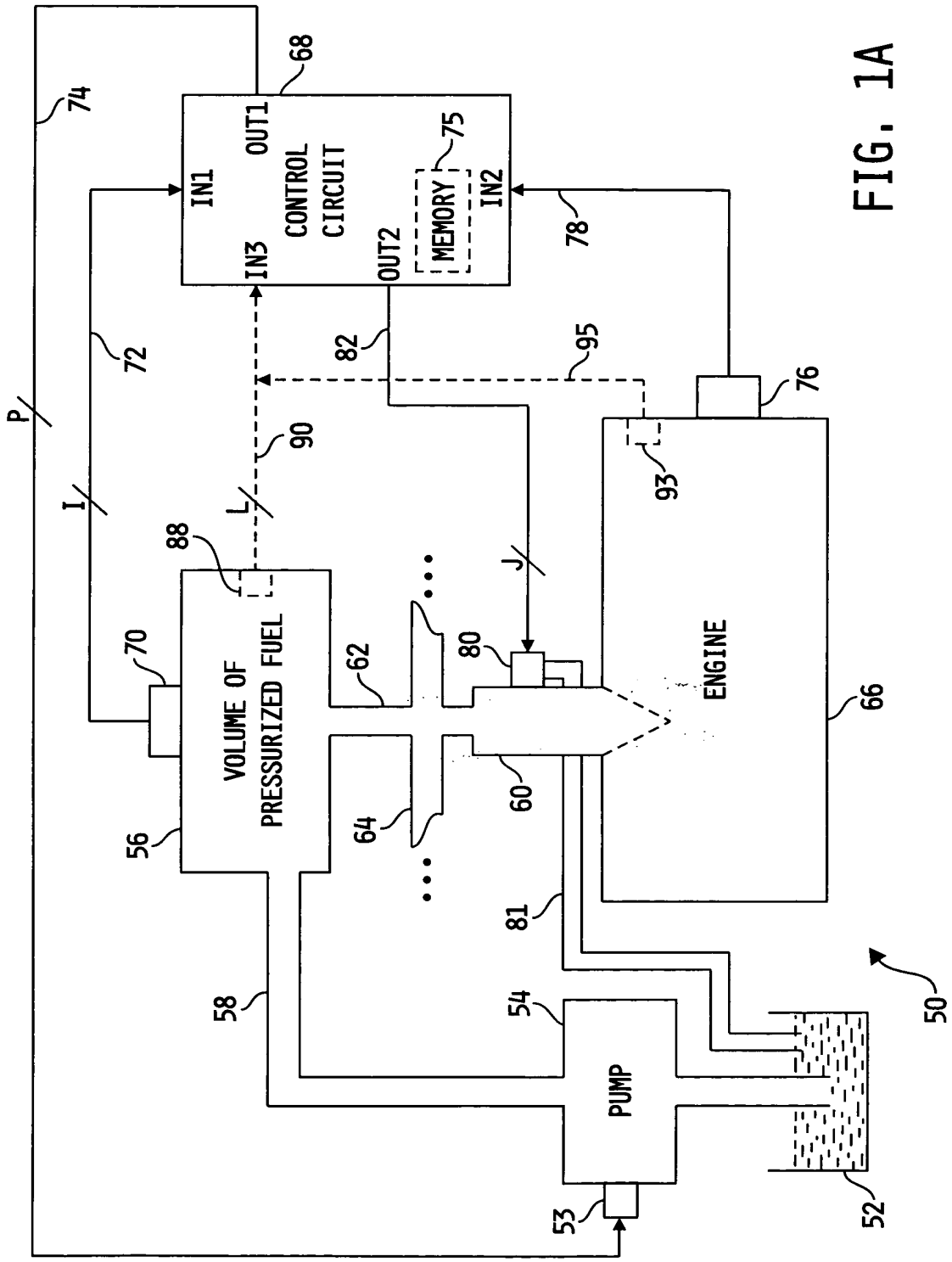

FIG. 1A

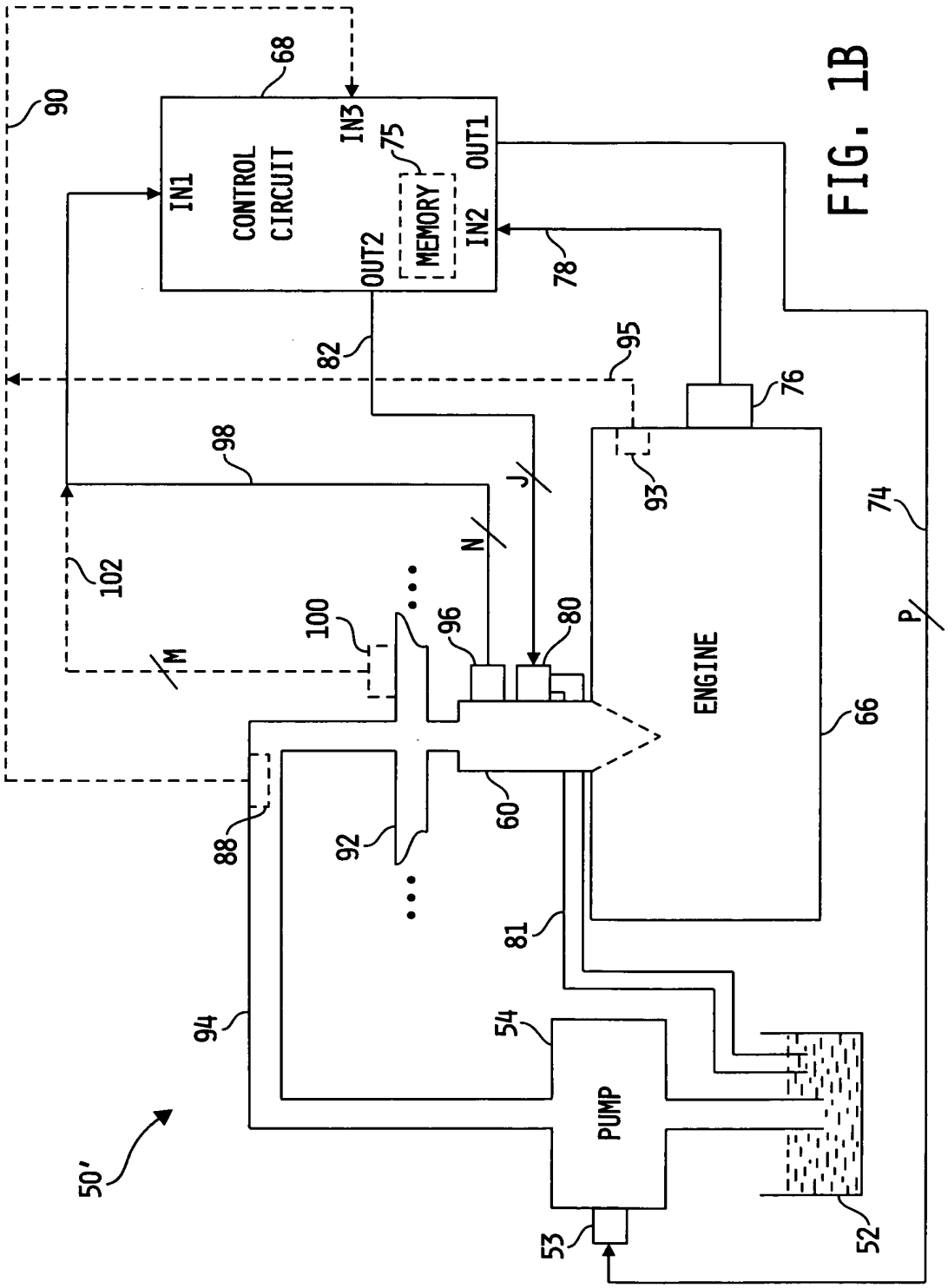
90
68
IN1
CONTROL CIRCUIT
IN3
75
MEMORY
OUT1
IN2
OUT2
78
82
95
76
98
93
74
J
N
102
100
96
80
M
P
ENGINE
66
88
92
60
81
94
54
PUMP
50'
53
52

FIG. 1B

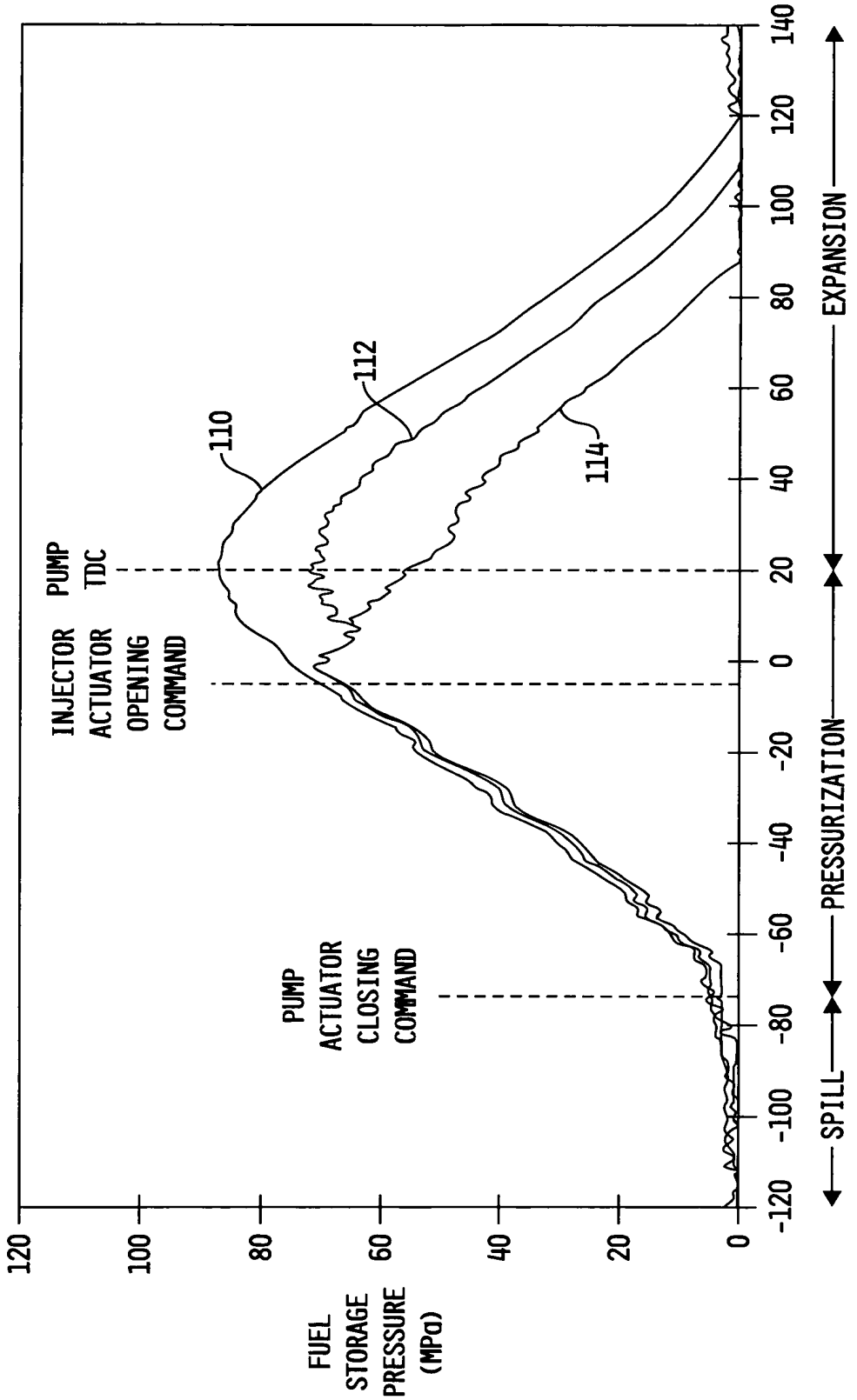
FUEL STORAGE PRESSURE (MPa)
120
100
80
60
40
20
0
110
112
114
INJECTOR ACTUATOR OPENING COMMAND
PUMP TDC
PUMP ACTUATOR CLOSING COMMAND
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
SPILL
PRESSURIZATION
EXPANSION
CRANK ANGLE (CRANK DEGREES AFTER TDC)

FIG. 2

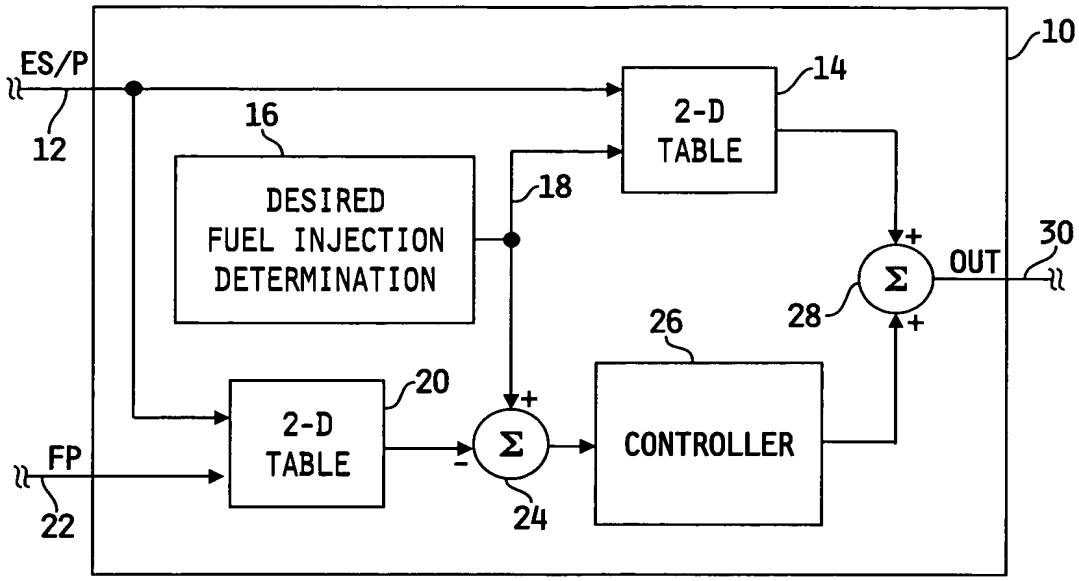

FIG. 3
(PRIOR ART)

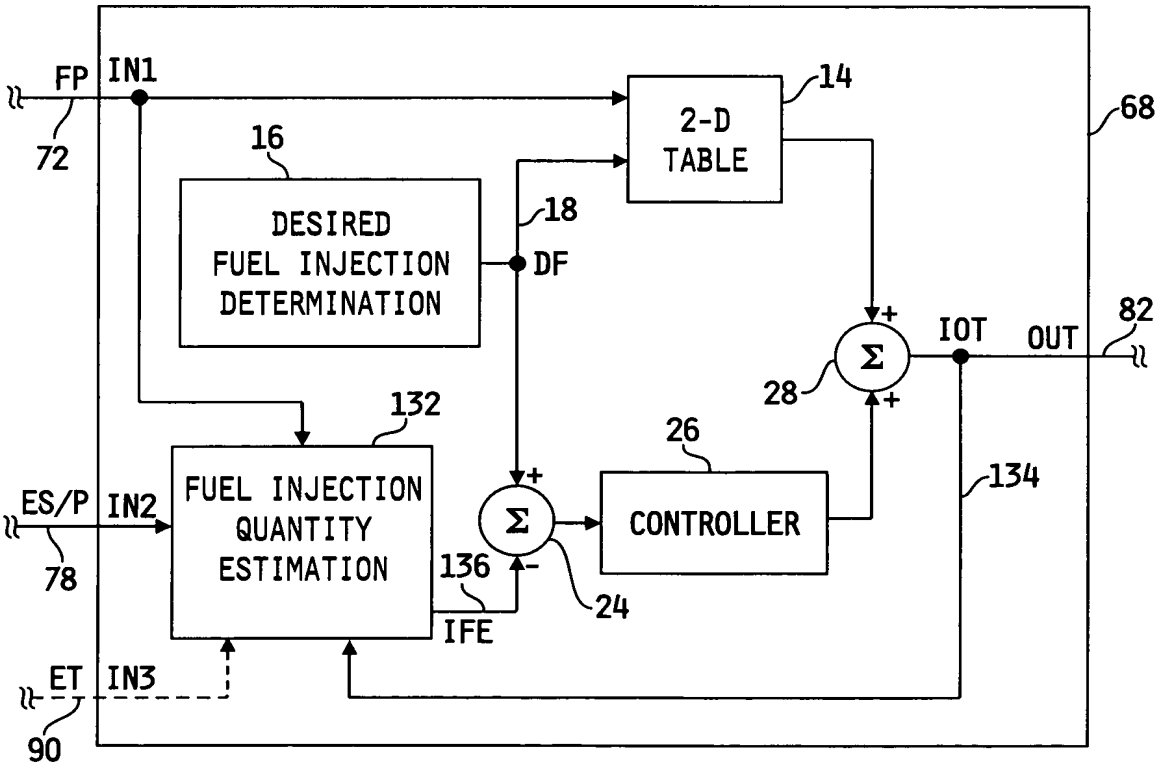

FIG. 4

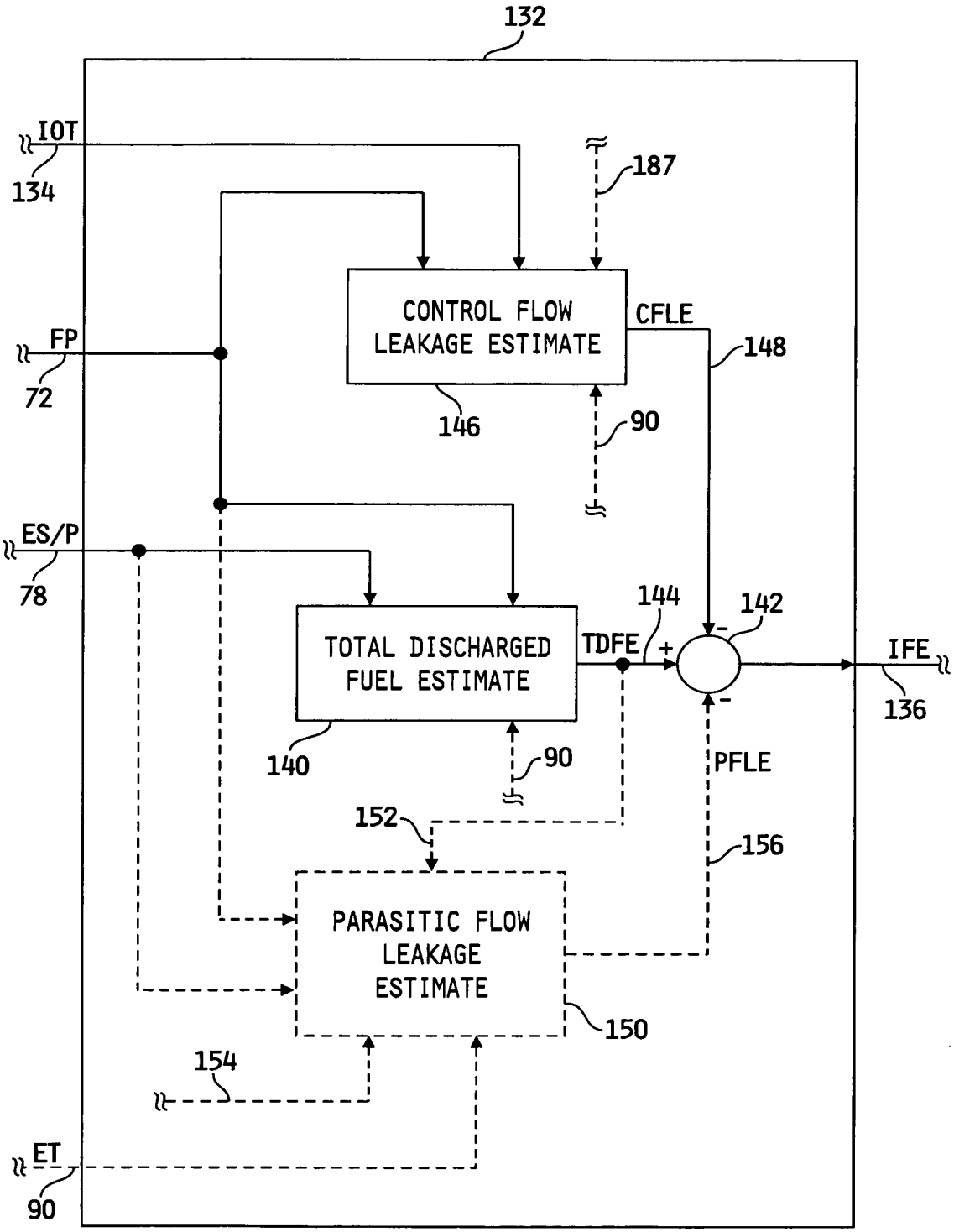
132
IOT
134
187
CONTROL FLOW LEAKAGE ESTIMATE
CFLE
148
FP
72
146
90
ES/P
78
144
142
TOTAL DISCHARGED FUEL ESTIMATE
TDFE
+
-
IFE
136
140
90
PFLE
152
156
PARASITIC FLOW LEAKAGE ESTIMATE
150
154
ET
90

FIG. 5

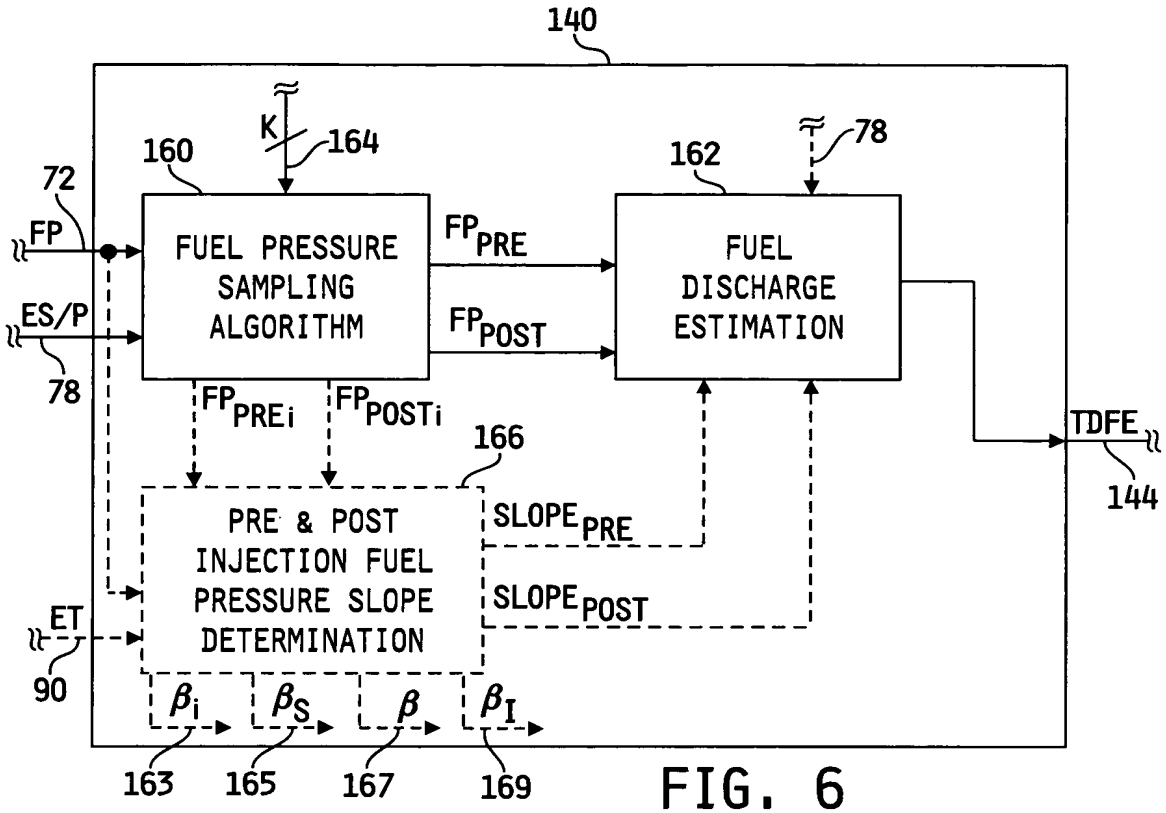
140
K
164
160
162
78
72
FP
FUEL PRESSURE SAMPLING ALGORITHM
FP_PRE
FP_POST
FUEL DISCHARGE ESTIMATION
ES/P
78
FP_PREi
FP_POSTi
166
TDFE
144
PRE & POST INJECTION FUEL PRESSURE SLOPE DETERMINATION
SLOPE_PRE
SLOPE_POST
ET
90
β_i
β_S
β
β_I
163
165
167
169

FIG. 6

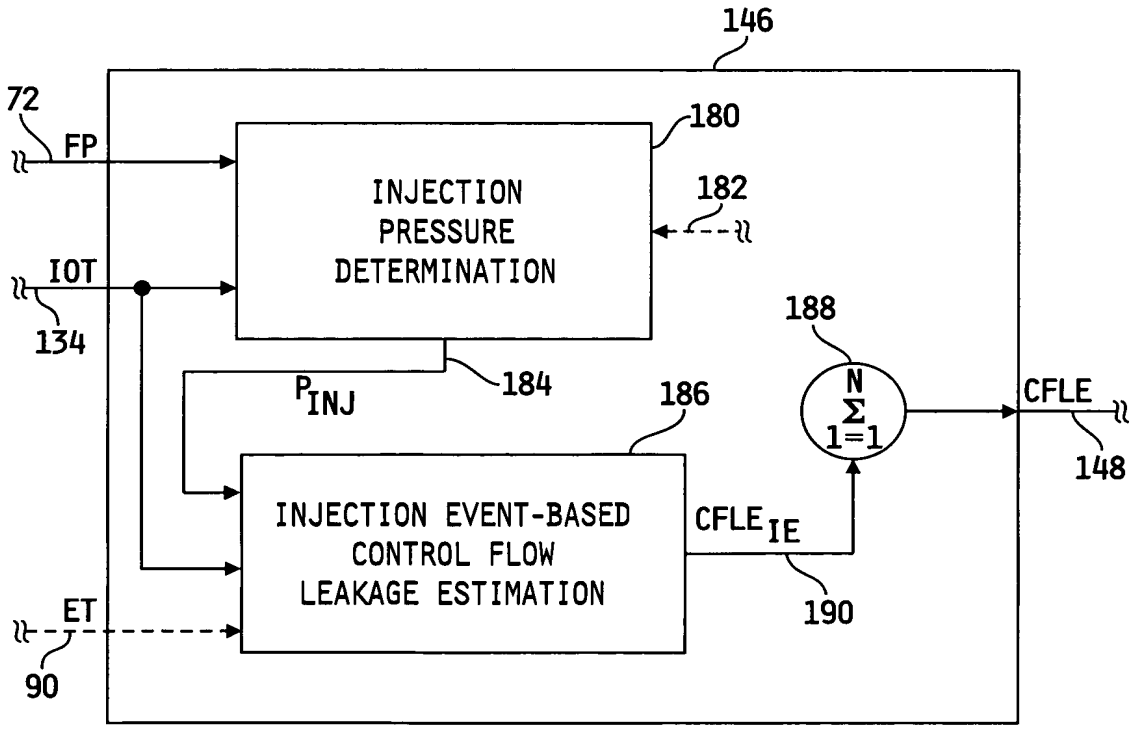
146
72
FP
180
INJECTION PRESSURE DETERMINATION
182
IOT
134
188
N
Σ
1=1
CFLE
148
P_INJ
184
186
INJECTION EVENT-BASED CONTROL FLOW LEAKAGE ESTIMATION
CFLE_IE
190
ET
90

FIG. 14

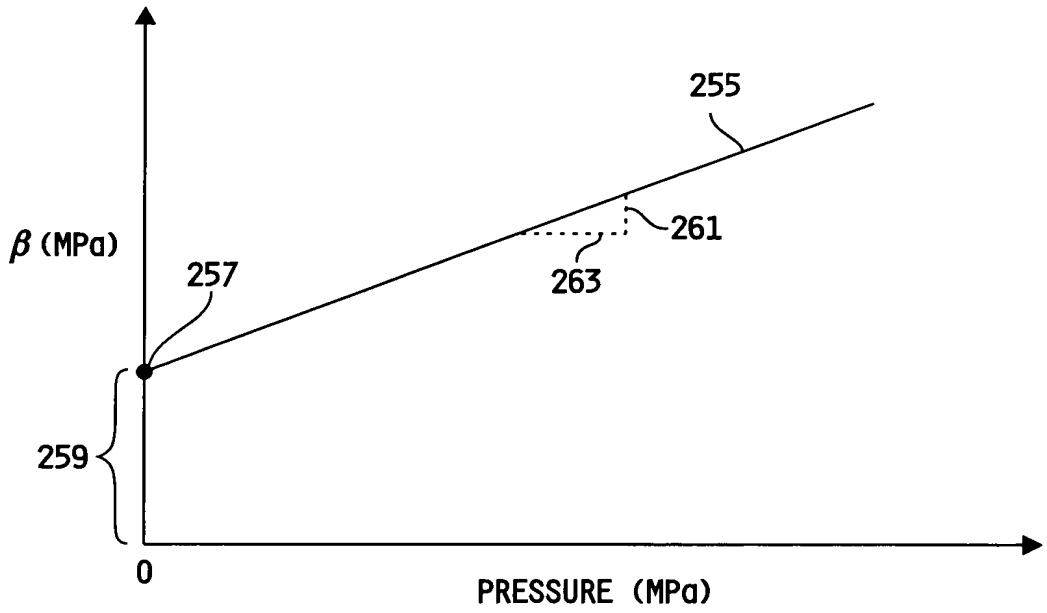
255
β (MPa)
261
257
263
259
0
PRESSURE (MPa)

FIG. 7

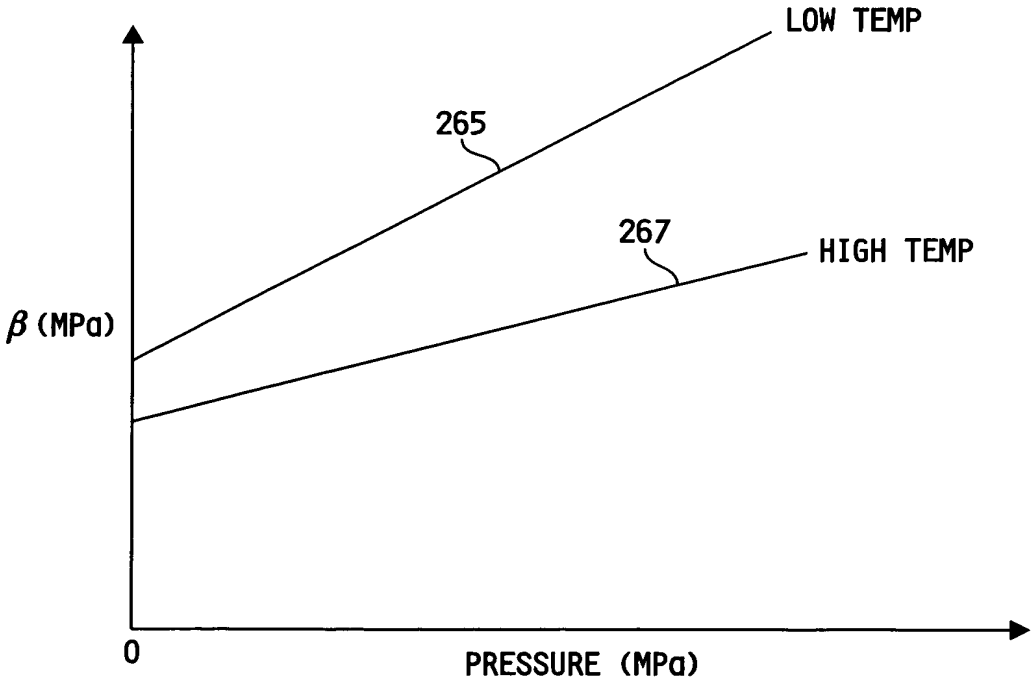
LOW TEMP
265
267
HIGH TEMP
β (MPa)
0
PRESSURE (MPa)

FIG. 8

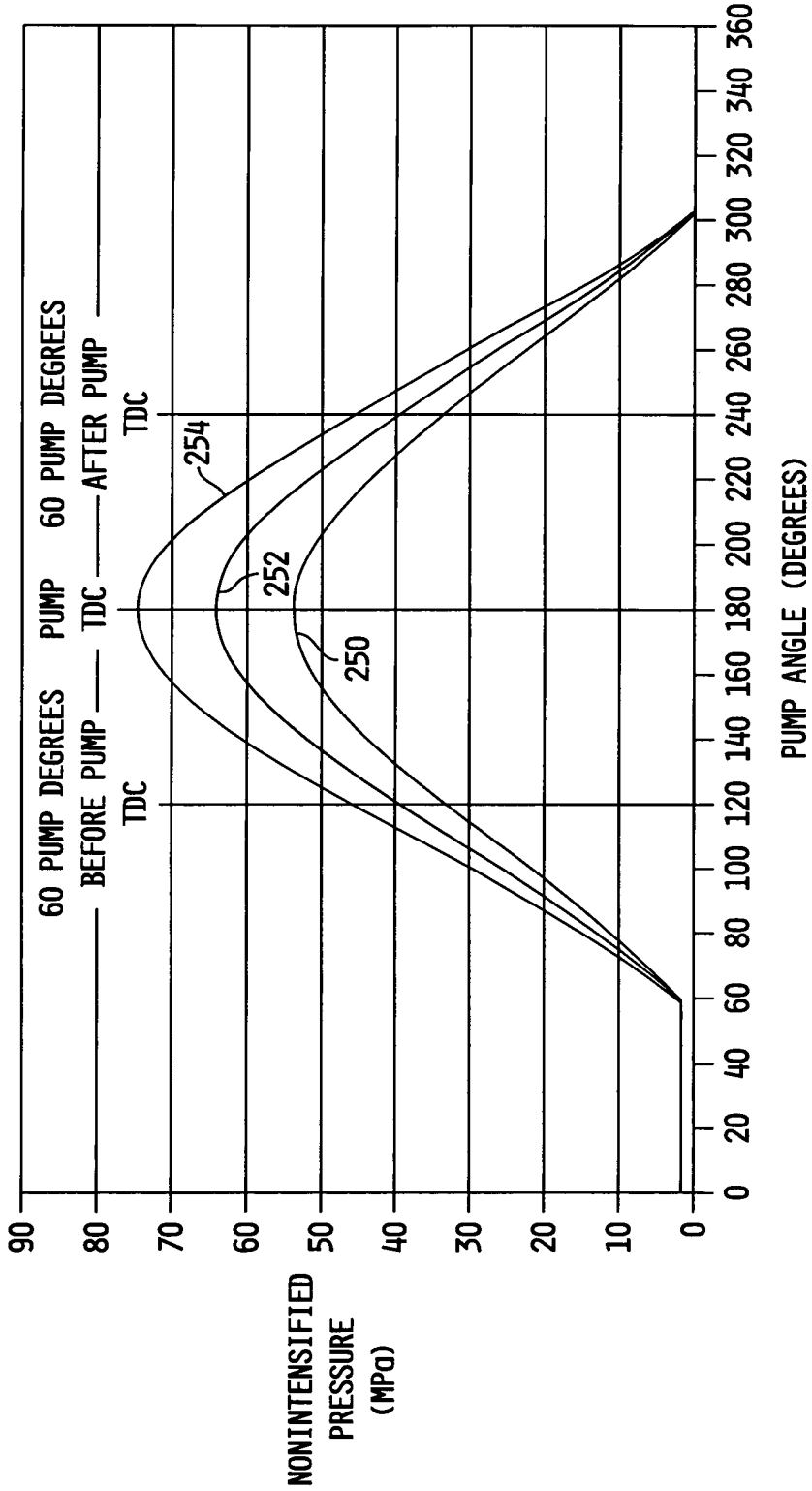
60 PUMP DEGREES BEFORE PUMP
PUMP
TDC
60 PUMP DEGREES AFTER PUMP
TDC
TDC
254
252
250
NONINTENSIFIED PRESSURE (MPa)
PUMP ANGLE (DEGREES)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

FIG. 9

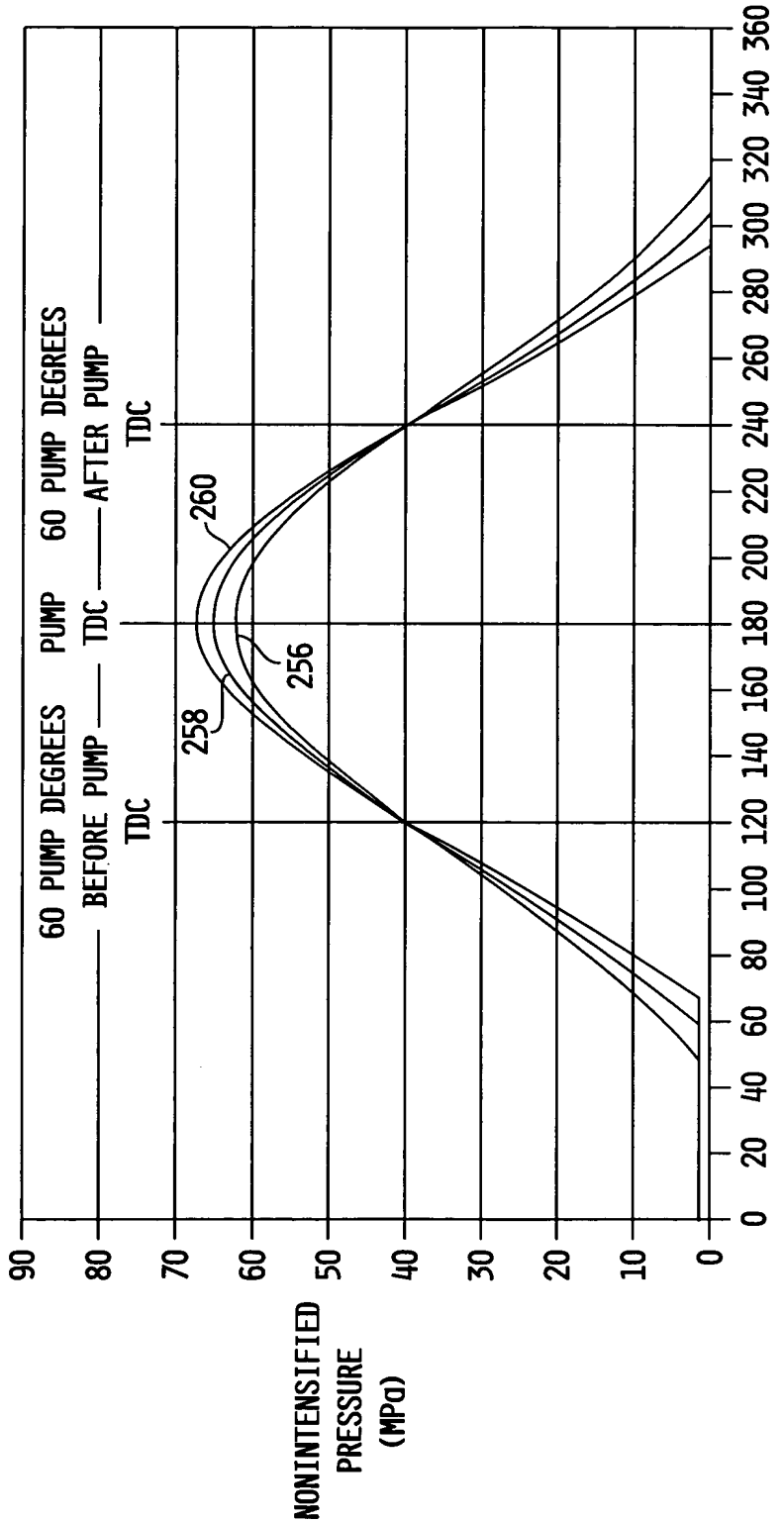
60 PUMP DEGREES PUMP 60 PUMP DEGREES
BEFORE PUMP — TDC — AFTER PUMP
TDC
TDC
260
256
258
NONINTENSIFIED PRESSURE (MPa)
PUMP ANGLE (DEGREES)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

FIG. 10

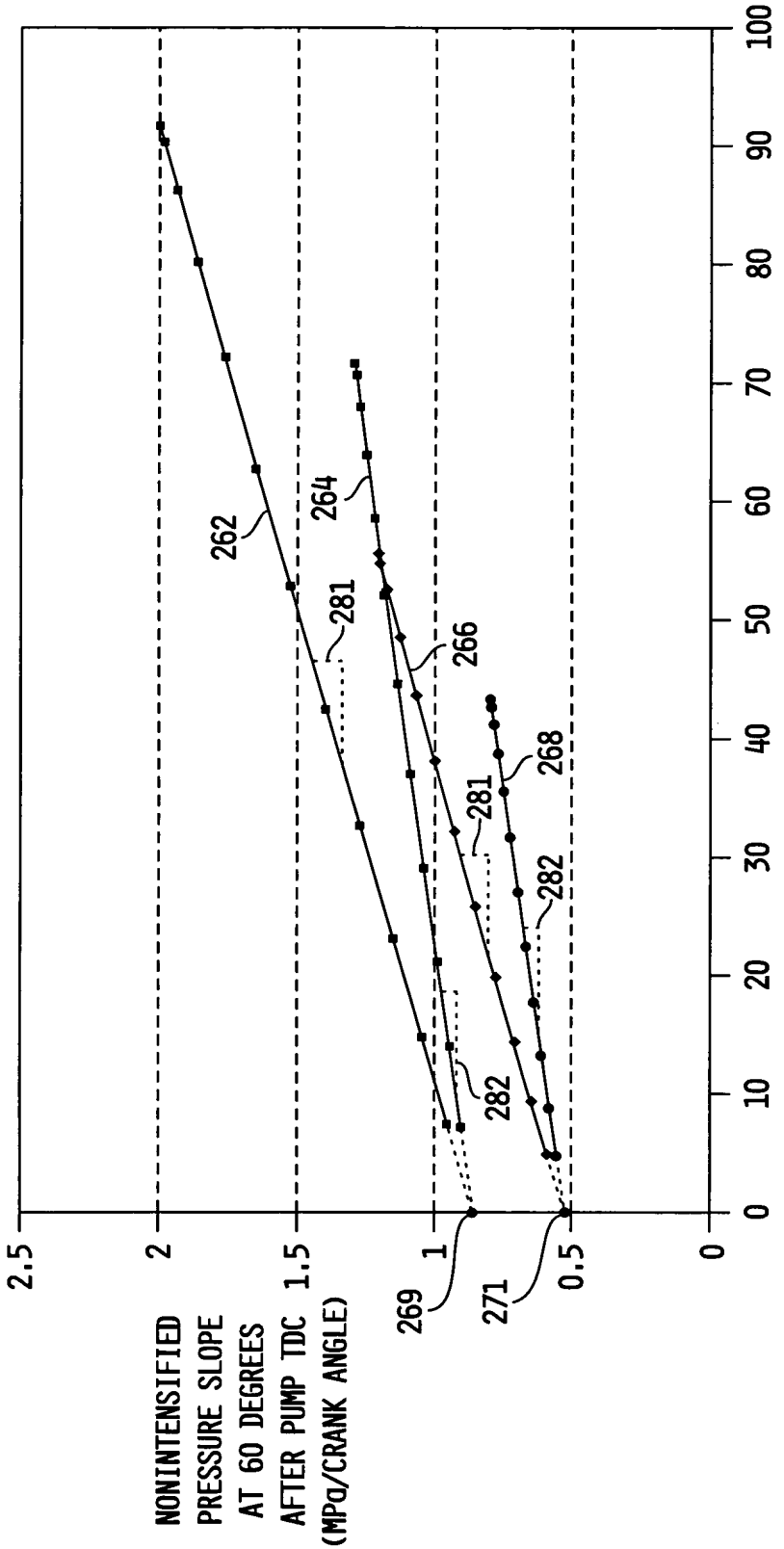
NONINTENSIFIED PRESSURE SLOPE AT 60 DEGREES AFTER PUMP TDC (MPa/CRANK ANGLE)
2.5
2
1.5
1
0.5
0
NONINTENSIFIED PRESSURE AT 60 DEGREES AFTER PUMP TDC (MPa)
0
10
20
30
40
50
60
70
80
90
100
262
264
266
268
269
271
281
281
282
282

FIG. 11

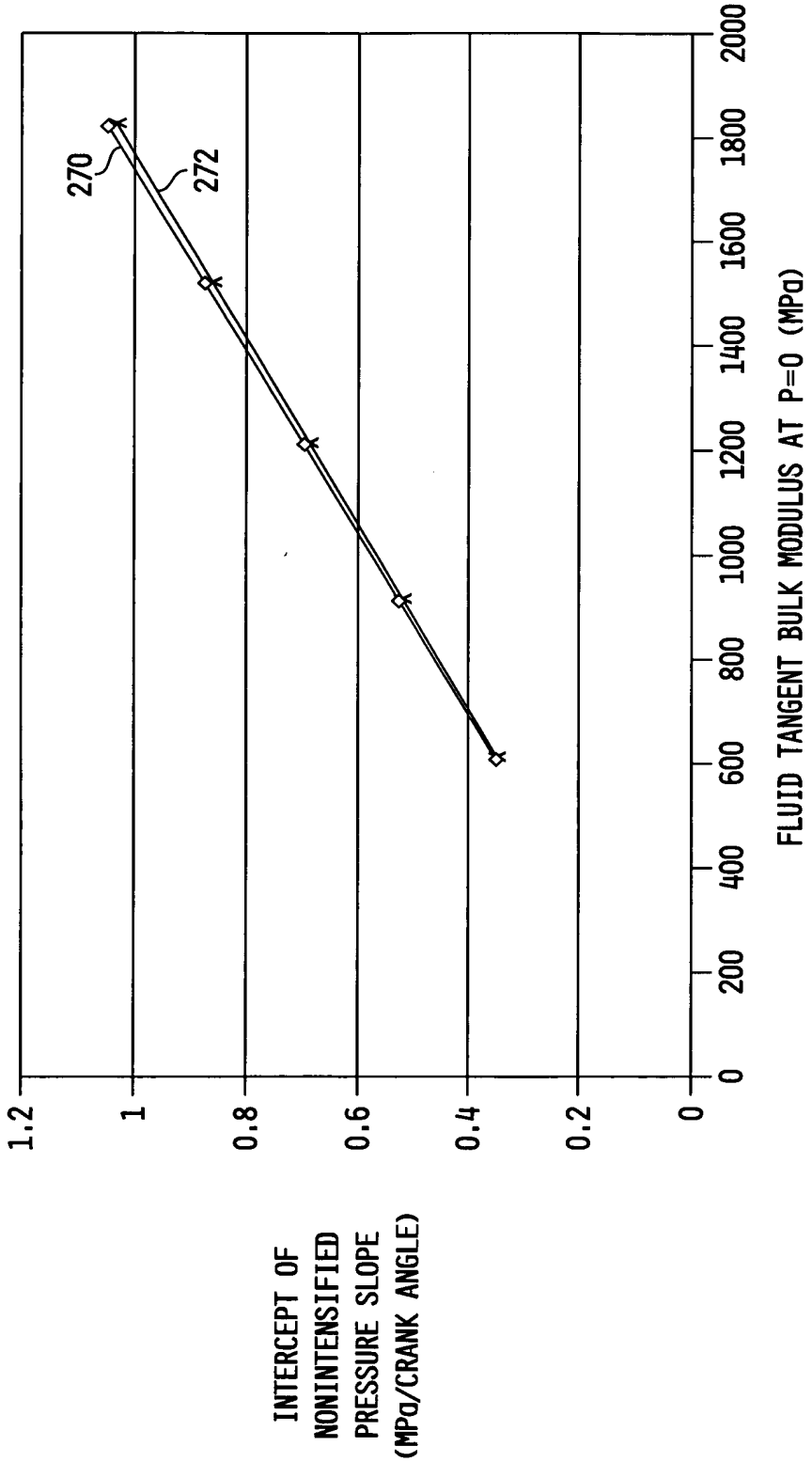
270
272
INTERCEPT OF NONINTENSIFIED PRESSURE SLOPE (MPa/CRANK ANGLE)
1.2
1
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
FLUID TANGENT BULK MODULUS AT P=0 (MPa)

FIG. 12A

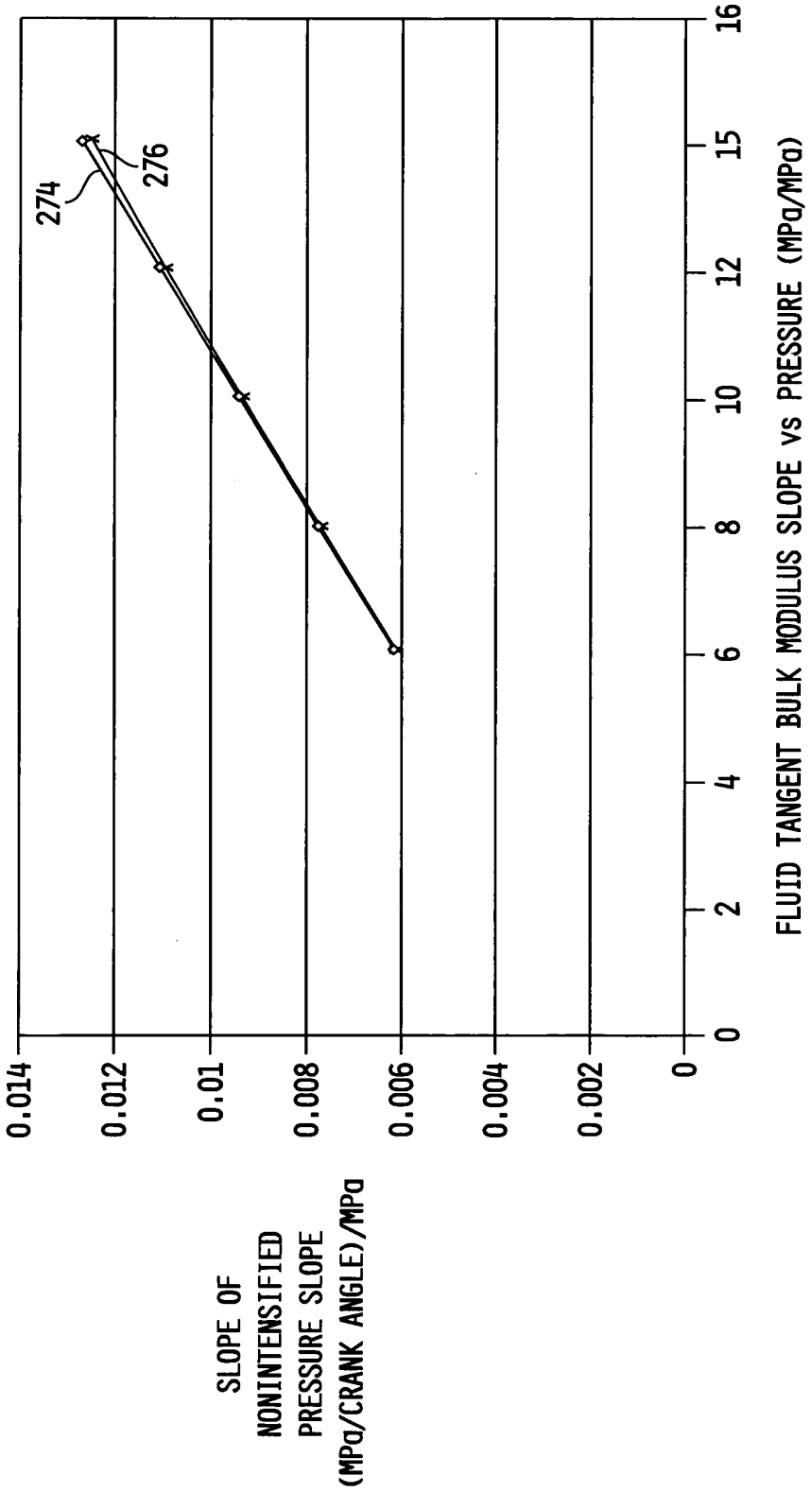
274
276
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
SLOPE OF
NONINTENSIFIED
PRESSURE SLOPE
(MPa/CRANK ANGLE)/MPa
0
2
4
6
8
10
12
15
16
FLUID TANGENT BULK MODULUS SLOPE vs PRESSURE (MPa/MPa)

FIG. 12B

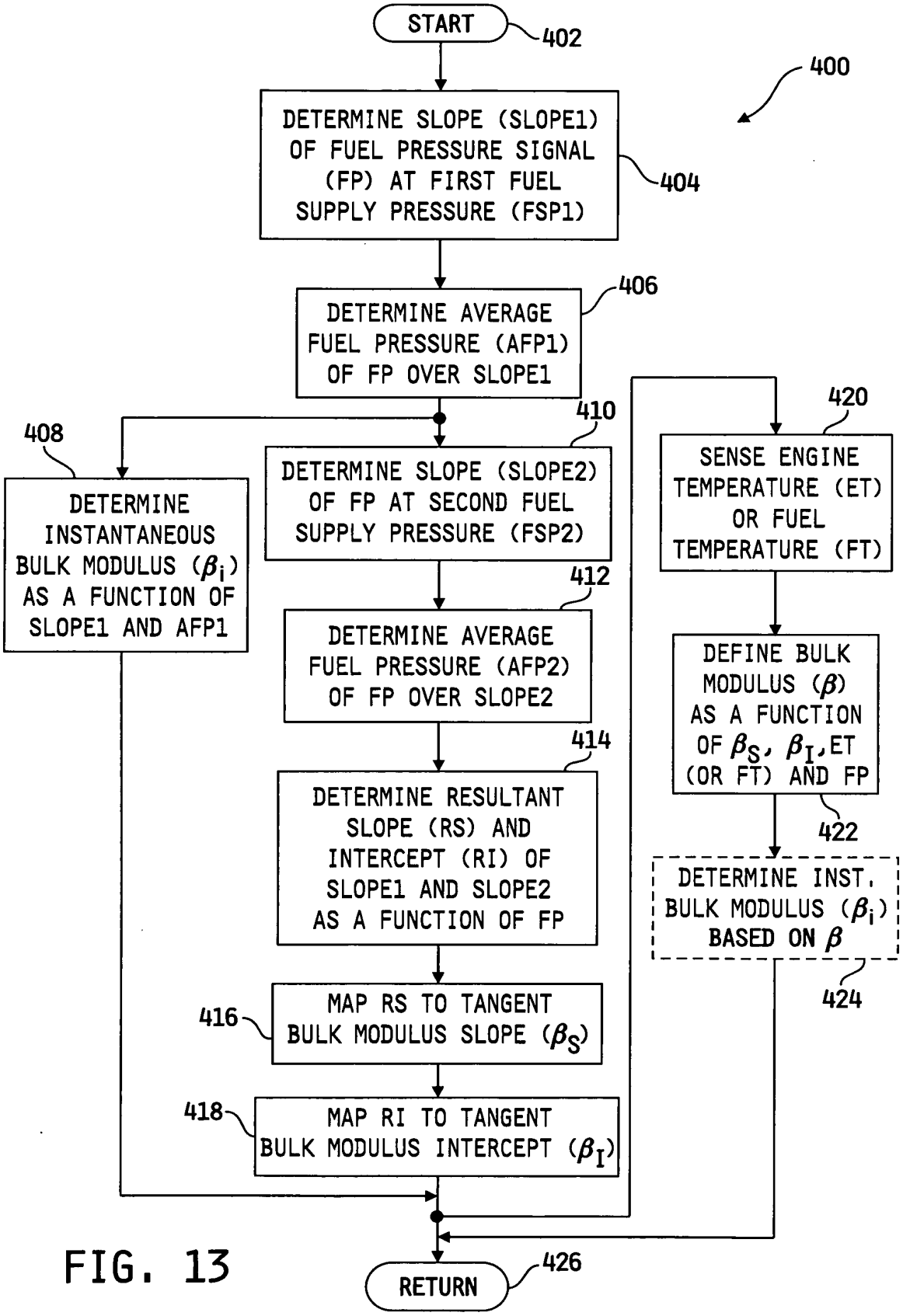
START
402
400
DETERMINE SLOPE (SLOPE1) OF FUEL PRESSURE SIGNAL (FP) AT FIRST FUEL SUPPLY PRESSURE (FSP1)
404
DETERMINE AVERAGE FUEL PRESSURE (AFP1) OF FP OVER SLOPE1
406
408
DETERMINE INSTANTANEOUS BULK MODULUS (β_i) AS A FUNCTION OF SLOPE1 AND AFP1
410
DETERMINE SLOPE (SLOPE2) OF FP AT SECOND FUEL SUPPLY PRESSURE (FSP2)
412
DETERMINE AVERAGE FUEL PRESSURE (AFP2) OF FP OVER SLOPE2
414
DETERMINE RESULTANT SLOPE (RS) AND INTERCEPT (RI) OF SLOPE1 AND SLOPE2 AS A FUNCTION OF FP
416
MAP RS TO TANGENT BULK MODULUS SLOPE (β_S)
418
MAP RI TO TANGENT BULK MODULUS INTERCEPT (β_I)
420
SENSE ENGINE TEMPERATURE (ET) OR FUEL TEMPERATURE (FT)
DEFINE BULK MODULUS (β) AS A FUNCTION OF β_S, β_I, ET (OR FT) AND FP
422
DETERMINE INST. BULK MODULUS (β_i) BASED ON β
424
RETURN
426

FIG. 13

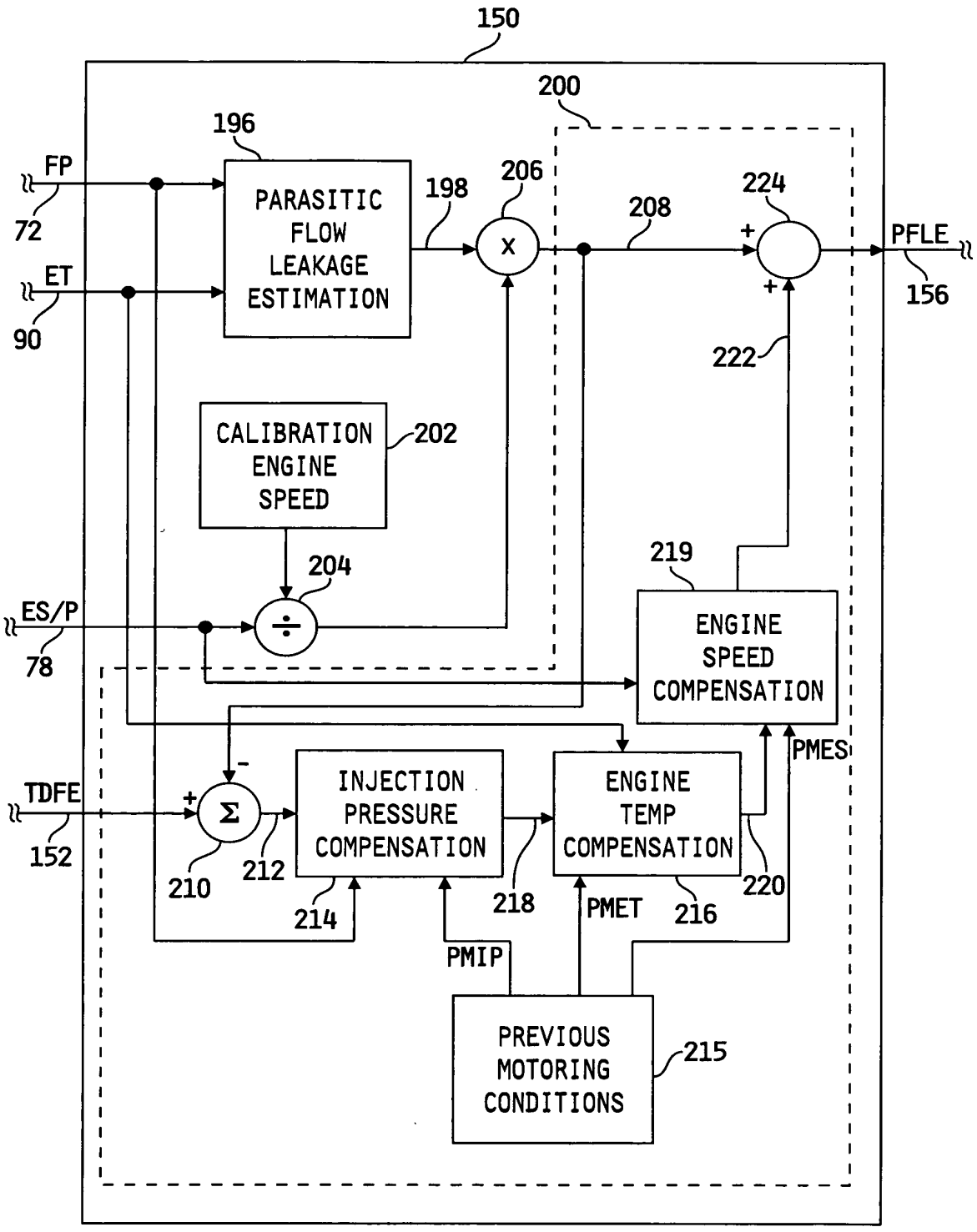
150
200
196
FP
72
ET
90
PARASITIC FLOW LEAKAGE ESTIMATION
198
206
X
208
224
+
+
PFLE
156
222
CALIBRATION ENGINE SPEED
202
204
ES/P
78
÷
219
ENGINE SPEED COMPENSATION
PMES
TDFE
152
+
-
Σ
210
212
INJECTION PRESSURE COMPENSATION
214
218
ENGINE TEMP COMPENSATION
220
PMET
216
PMIP
PREVIOUS MOTORING CONDITIONS
215

FIG. 15

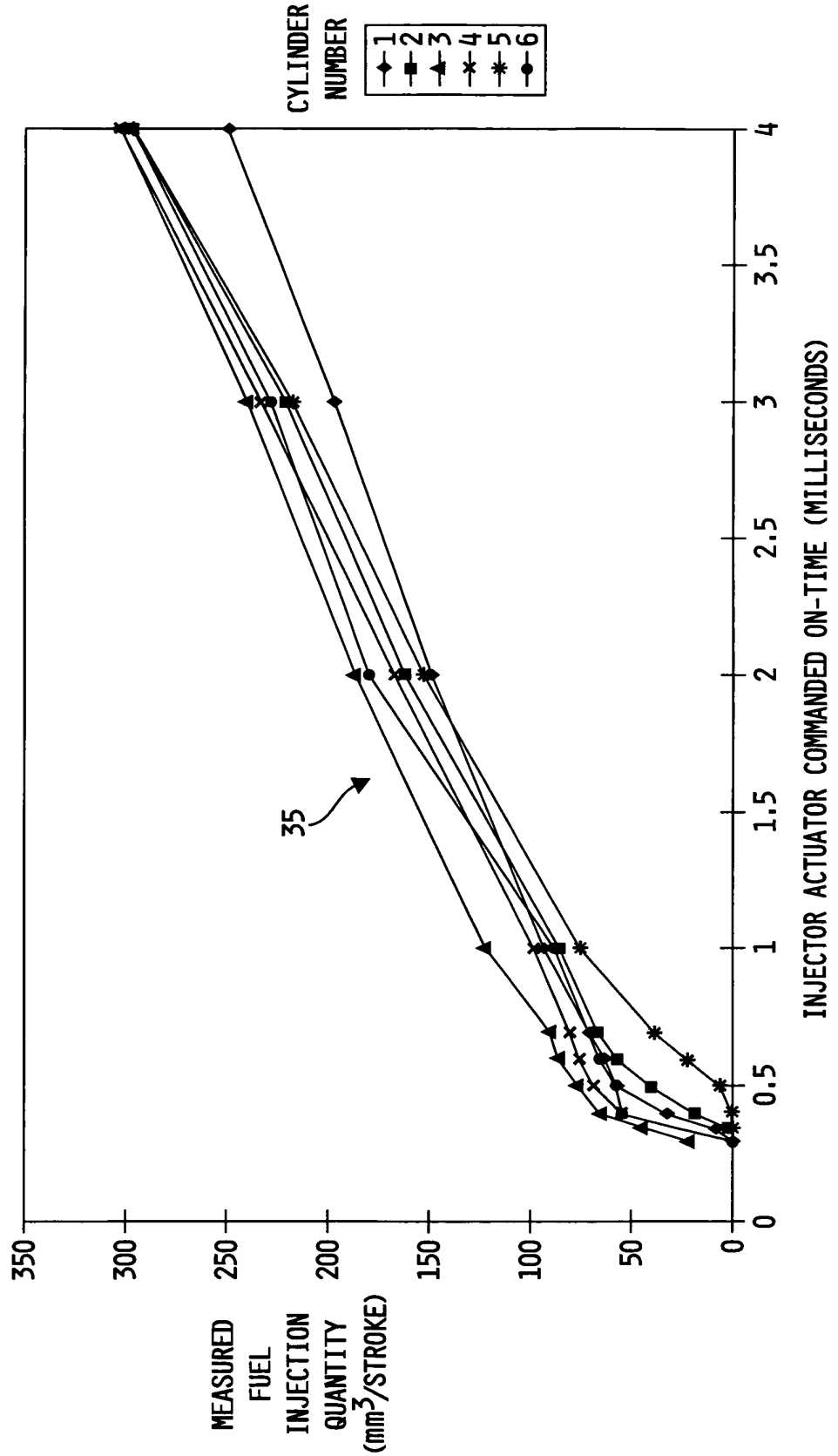

FIG. 16 (PRIOR ART)

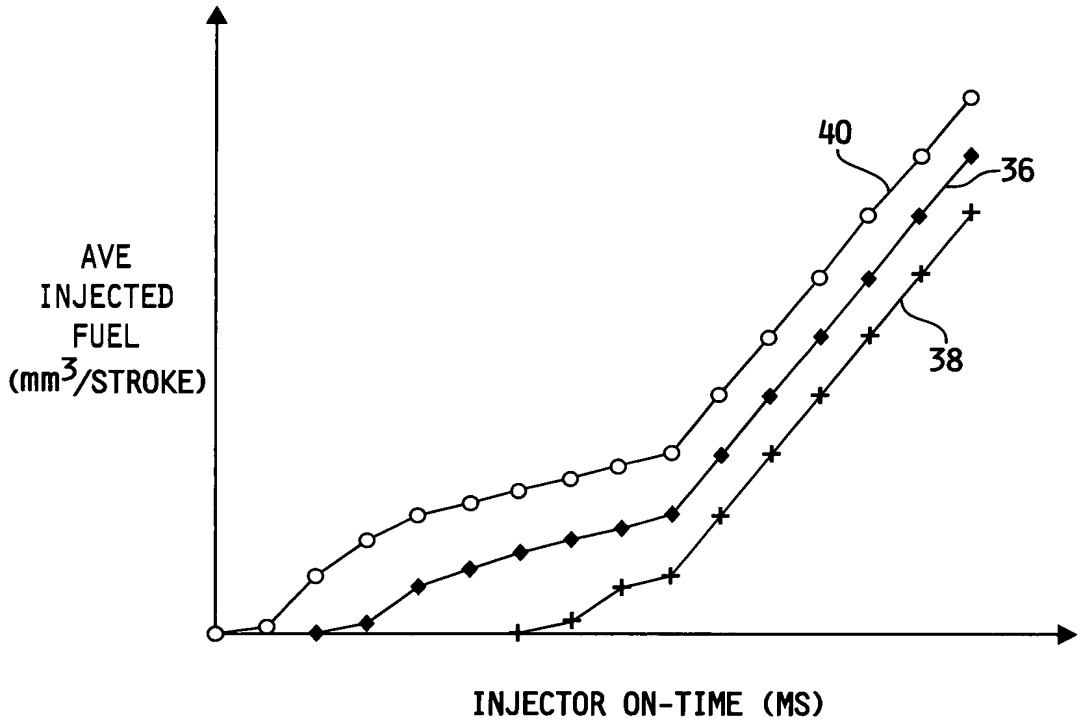

FIG. 17
(PRIOR ART)

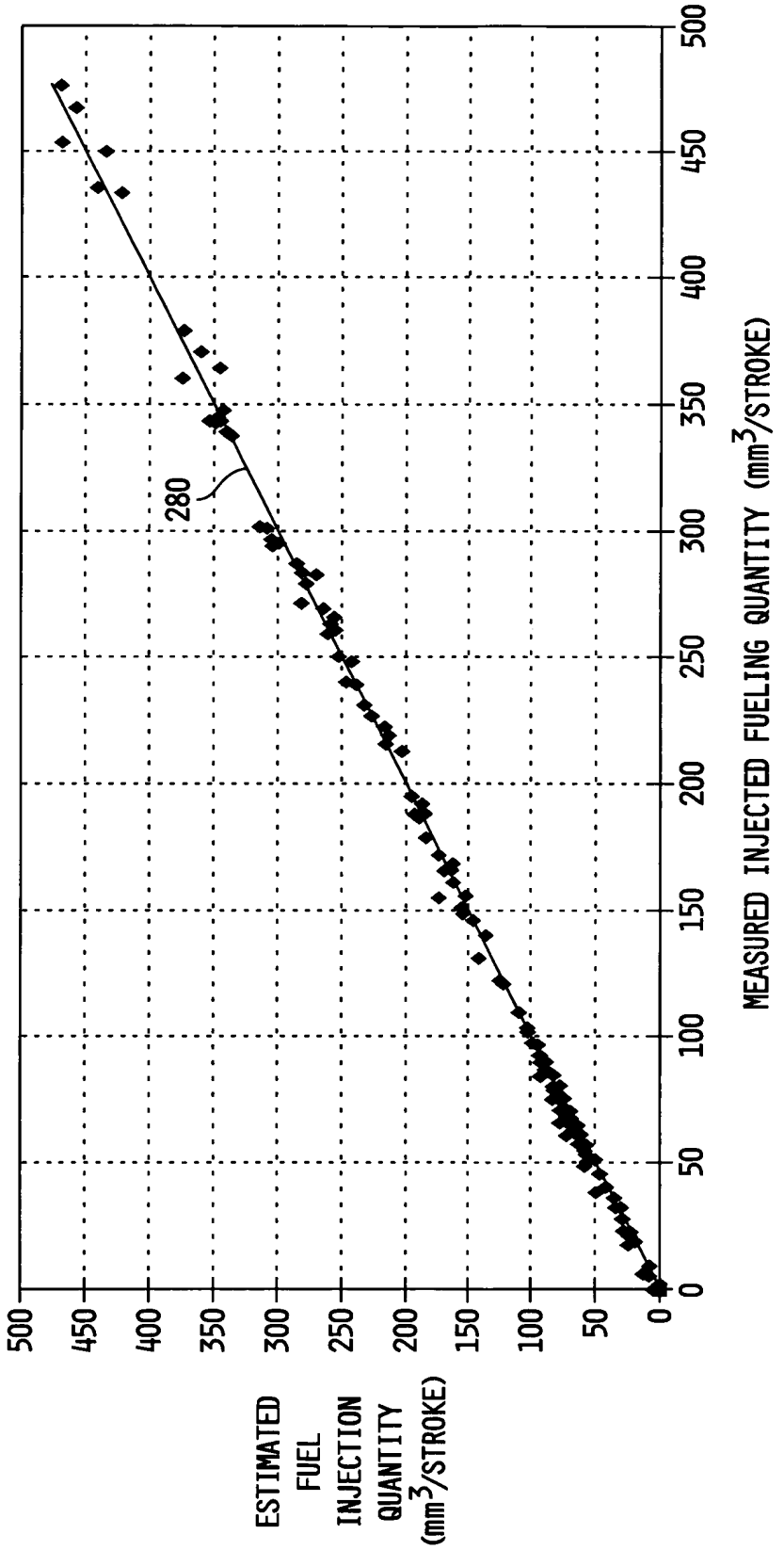
280
ESTIMATED FUEL INJECTION QUANTITY (mm^3/STROKE)
MEASURED INJECTED FUELING QUANTITY (mm^3/STROKE)
0
50
100
150
200
250
300
350
400
450
500

FIG. 18

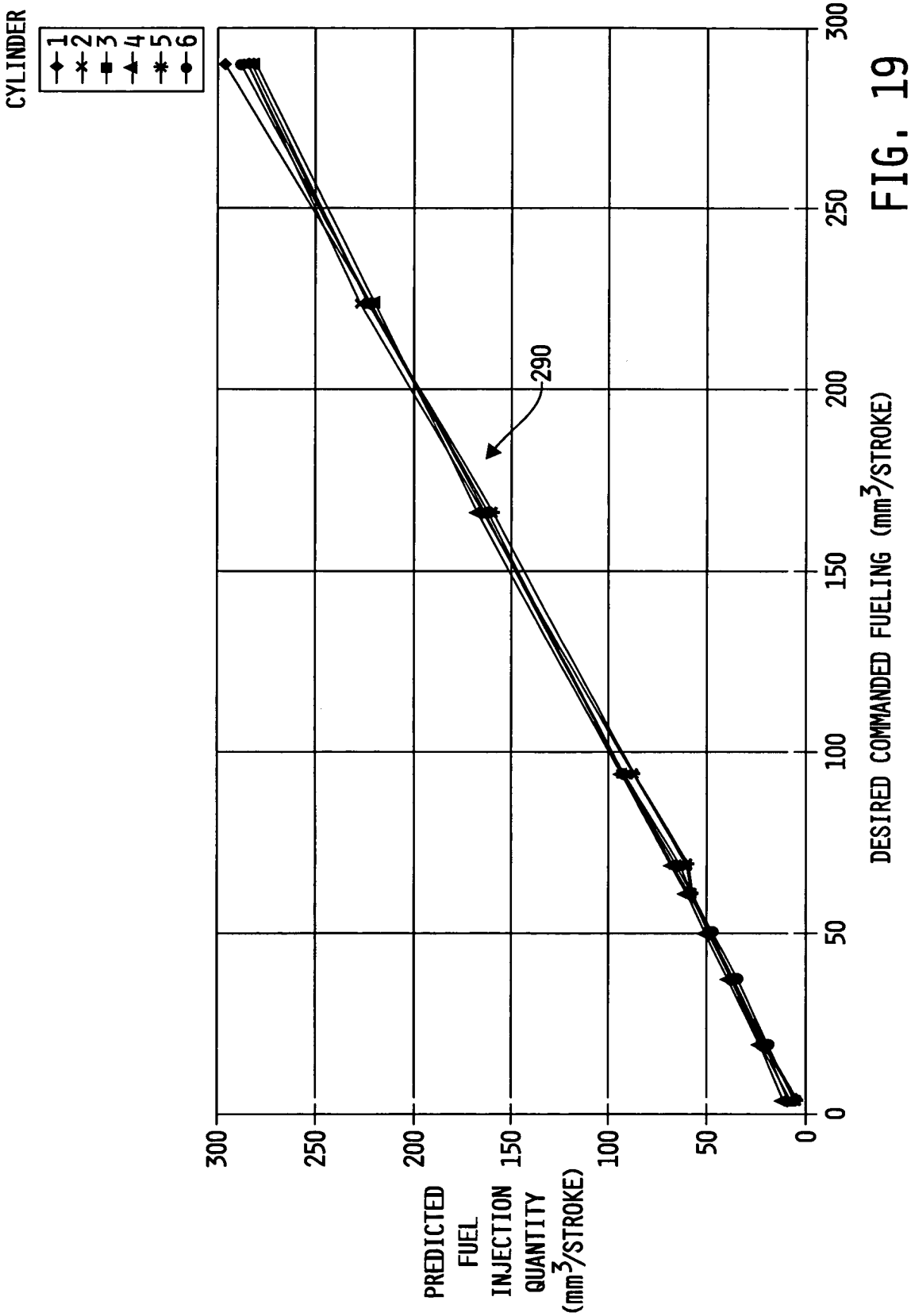
CYLINDER
1
2
3
4
5
6
290
PREDICTED FUEL INJECTION QUANTITY (mm3/STROKE)
DESIRED COMMANDED FUELING (mm3/STROKE)
0
50
100
150
200
250
300

FIG. 19

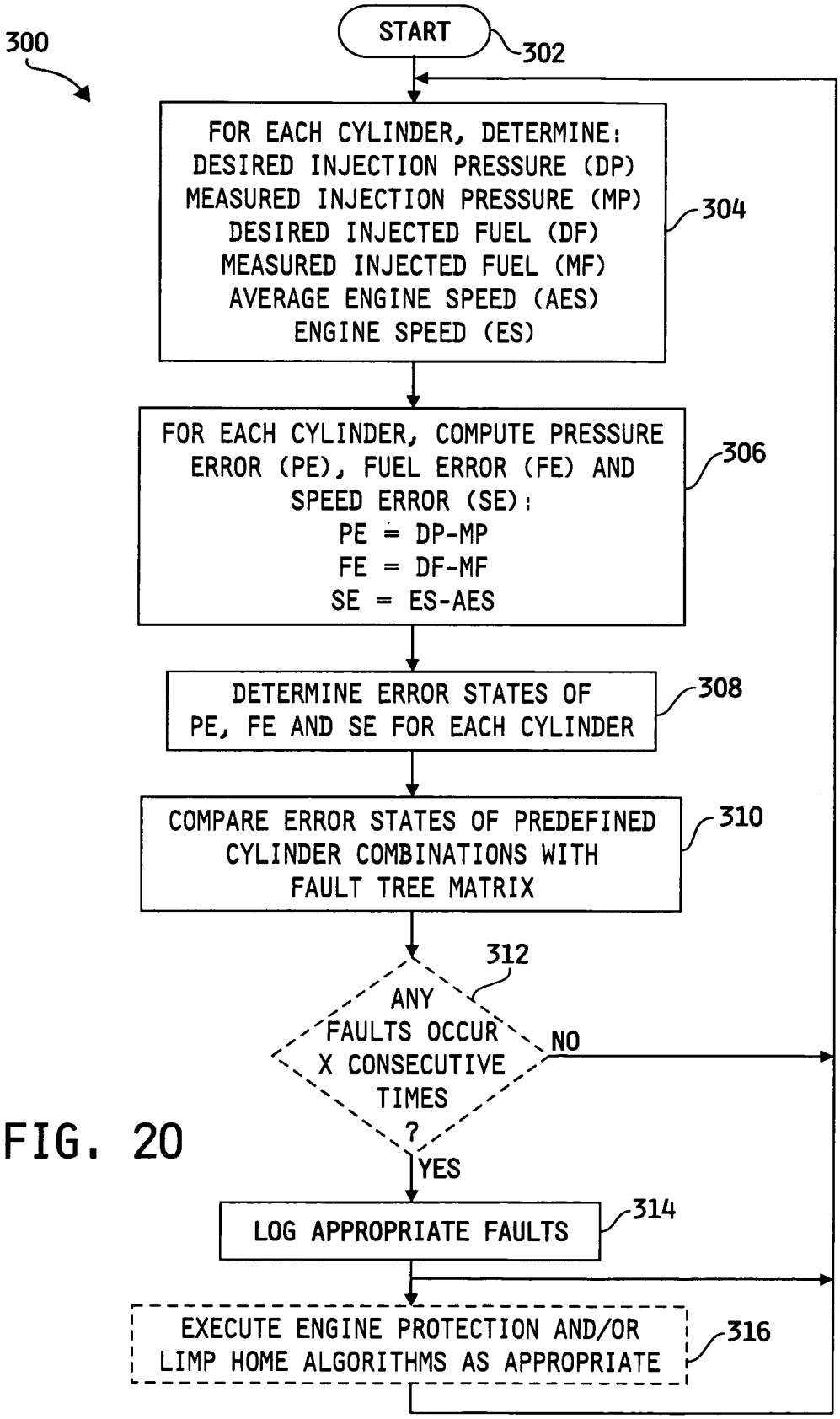
300
START
302
FOR EACH CYLINDER, DETERMINE:
DESIRED INJECTION PRESSURE (DP)
MEASURED INJECTION PRESSURE (MP)
DESIRED INJECTED FUEL (DF)
MEASURED INJECTED FUEL (MF)
AVERAGE ENGINE SPEED (AES)
ENGINE SPEED (ES)
304
FOR EACH CYLINDER, COMPUTE PRESSURE
ERROR (PE), FUEL ERROR (FE) AND
SPEED ERROR (SE):
PE = DP-MP
FE = DF-MF
SE = ES-AES
306
DETERMINE ERROR STATES OF
PE, FE AND SE FOR EACH CYLINDER
308
COMPARE ERROR STATES OF PREDEFINED
CYLINDER COMBINATIONS WITH
FAULT TREE MATRIX
310
312
ANY
FAULTS OCCUR
X CONSECUTIVE
TIMES
?
NO
YES
LOG APPROPRIATE FAULTS
314
EXECUTE ENGINE PROTECTION AND/OR
LIMP HOME ALGORITHMS AS APPROPRIATE
316

FIG. 20

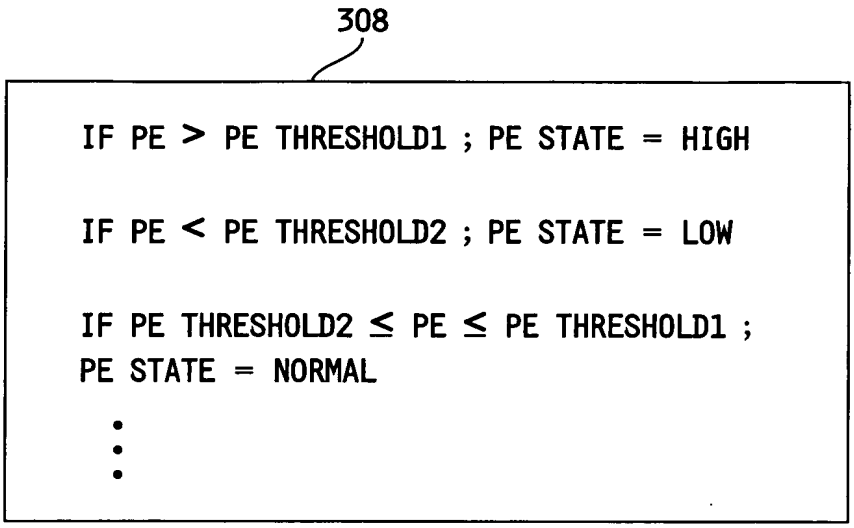

FIG. 21

310

CYL #	PE STATE	FE STATE	SE STATE	FAULT
1	LOW	HIGH	HIGH	OVERFUELING
2	NORMAL	NORMAL	NORMAL	CYL #1
3	NORMAL	NORMAL	NORMAL	
1	NORMAL/LOW	HIGH	NORMAL	CONTINUOUSLY
2	NORMAL/LOW	HIGH	NORMAL	OVERFUELING
3	NORMAL/LOW	HIGH	HIGH	CYL # 3

FIG. 22

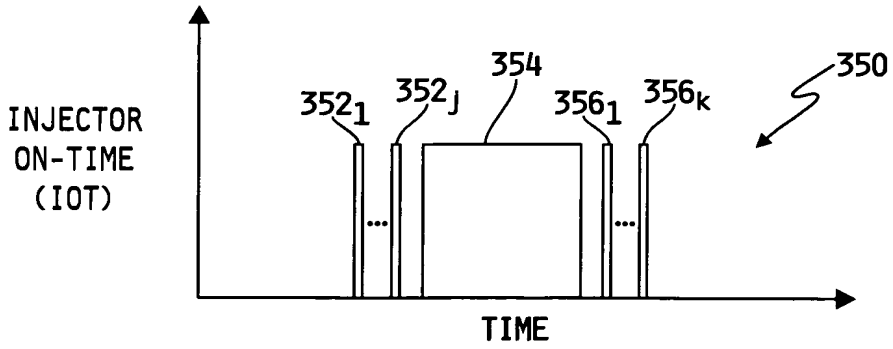

FIG. 23

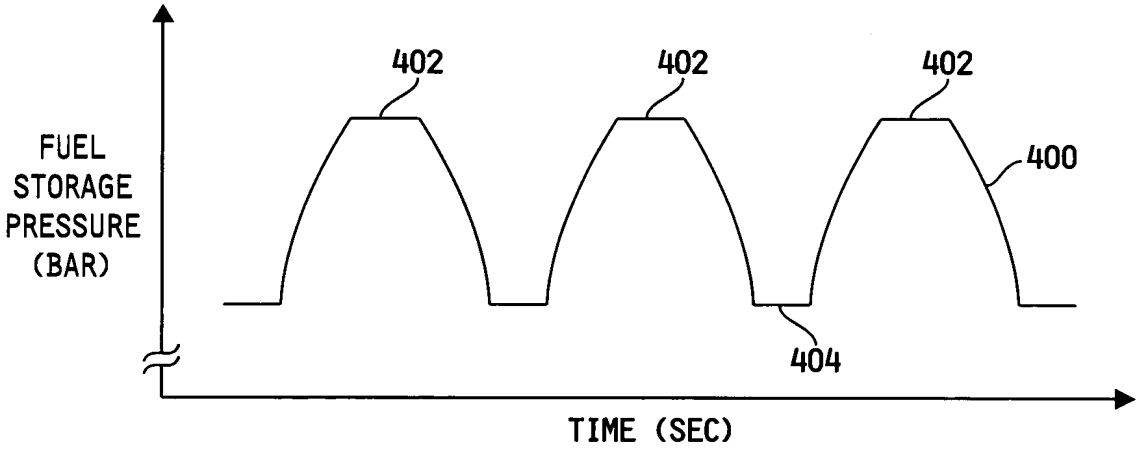

FIG. 24A

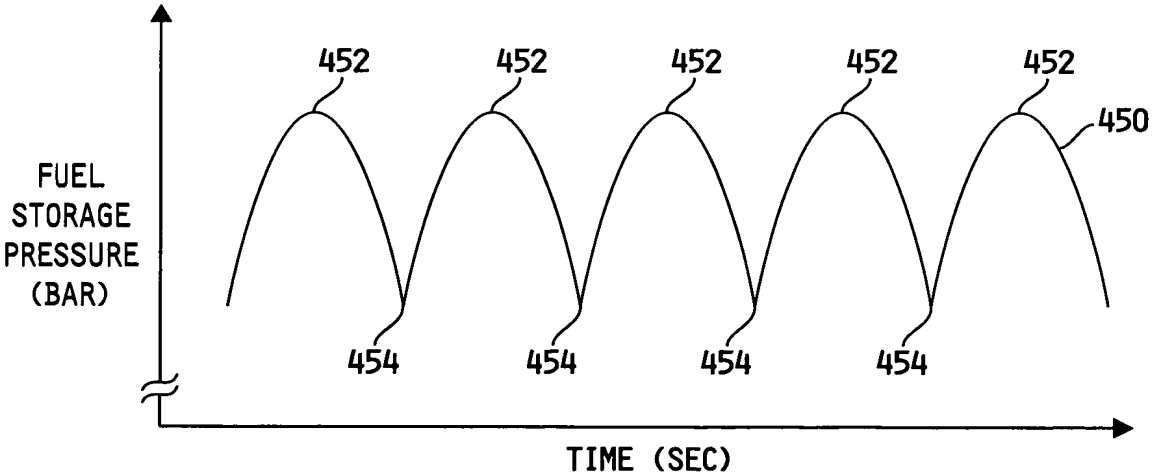

FIG. 24B

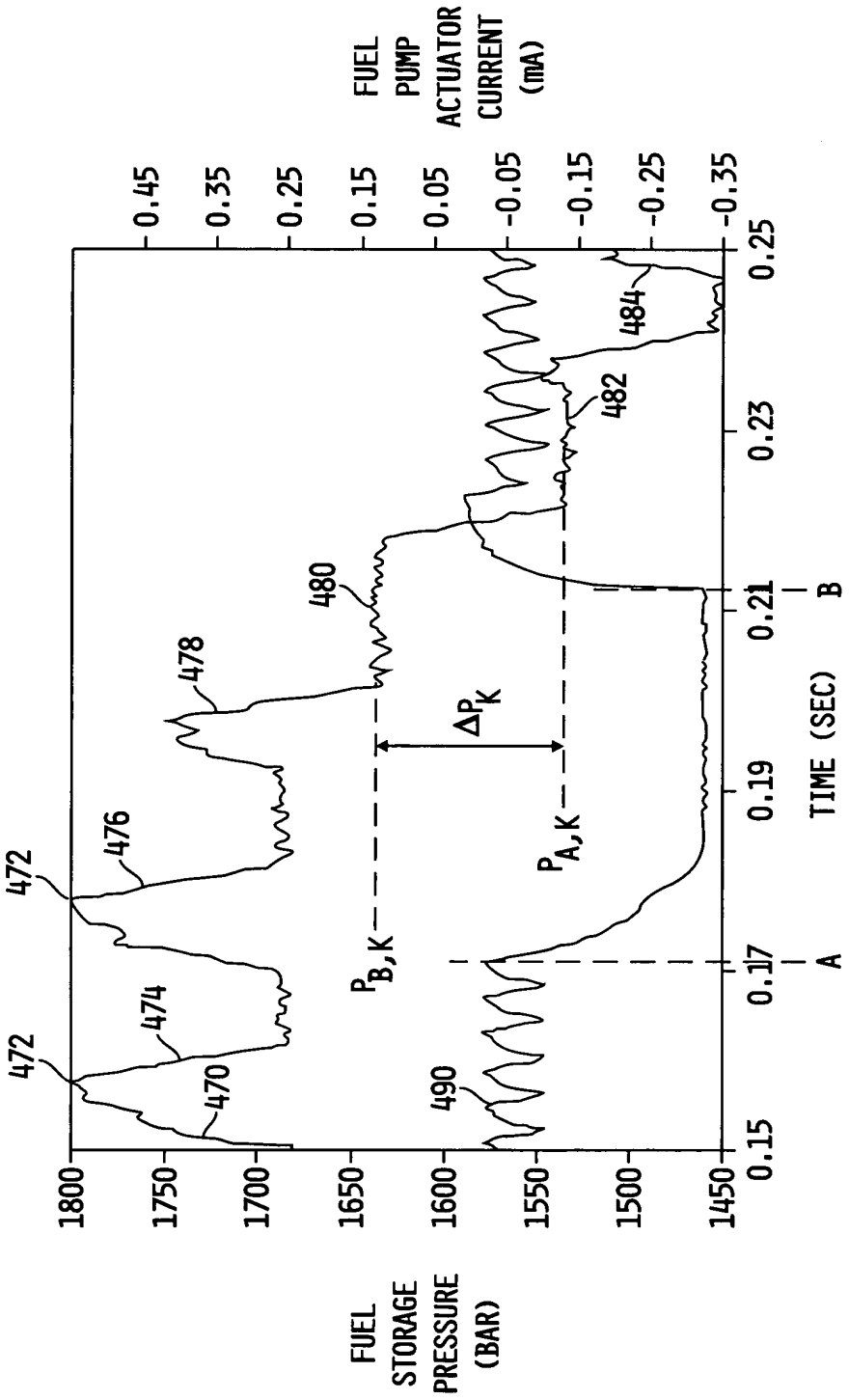
FUEL PUMP ACTUATOR CURRENT (mA)
0.45
0.35
0.25
0.15
0.05
-0.05
-0.15
-0.25
-0.35
0.25
0.23
0.21
0.19
0.17
0.15
TIME (SEC)
A
B
FUEL STORAGE PRESSURE (BAR)
1800
1750
1700
1650
1600
1550
1500
1450
472
476
474
470
472
478
480
482
484
490
$P_{B,K}$
ΔP_K
$P_{A,K}$

FIG. 25

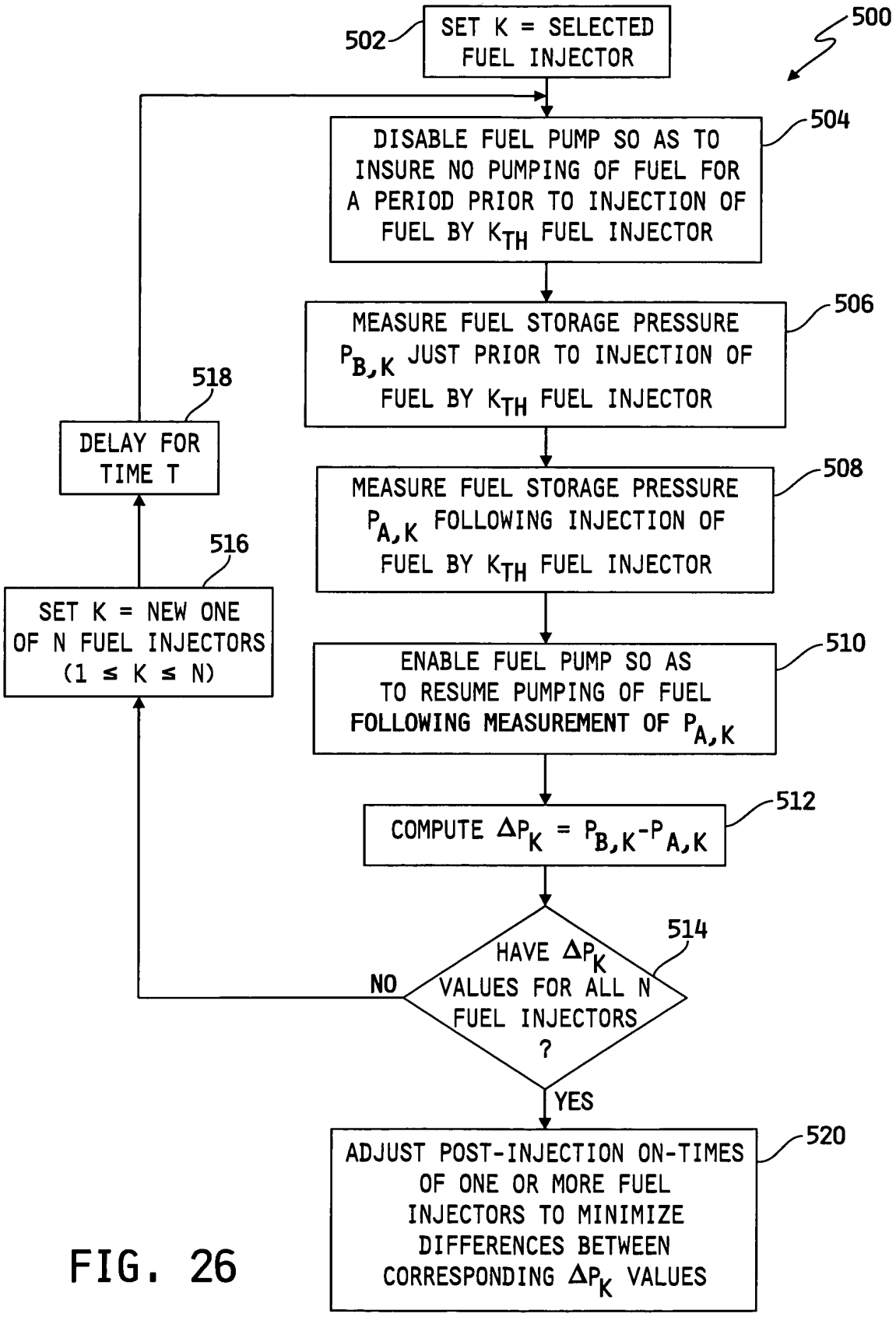
500
502
SET K = SELECTED FUEL INJECTOR
504
DISABLE FUEL PUMP SO AS TO INSURE NO PUMPING OF FUEL FOR A PERIOD PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
506
MEASURE FUEL STORAGE PRESSURE $P_{B,K}$ JUST PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
508
MEASURE FUEL STORAGE PRESSURE $P_{A,K}$ FOLLOWING INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
510
ENABLE FUEL PUMP SO AS TO RESUME PUMPING OF FUEL FOLLOWING MEASUREMENT OF $P_{A,K}$
512
COMPUTE $\Delta P_K = P_{B,K} - P_{A,K}$
514
HAVE ΔP_K VALUES FOR ALL N FUEL INJECTORS ?
NO
YES
516
SET K = NEW ONE OF N FUEL INJECTORS ($1 \leq K \leq N$)
518
DELAY FOR TIME T
520
ADJUST POST-INJECTION ON-TIMES OF ONE OR MORE FUEL INJECTORS TO MINIMIZE DIFFERENCES BETWEEN CORRESPONDING ΔP_K VALUES

FIG. 26

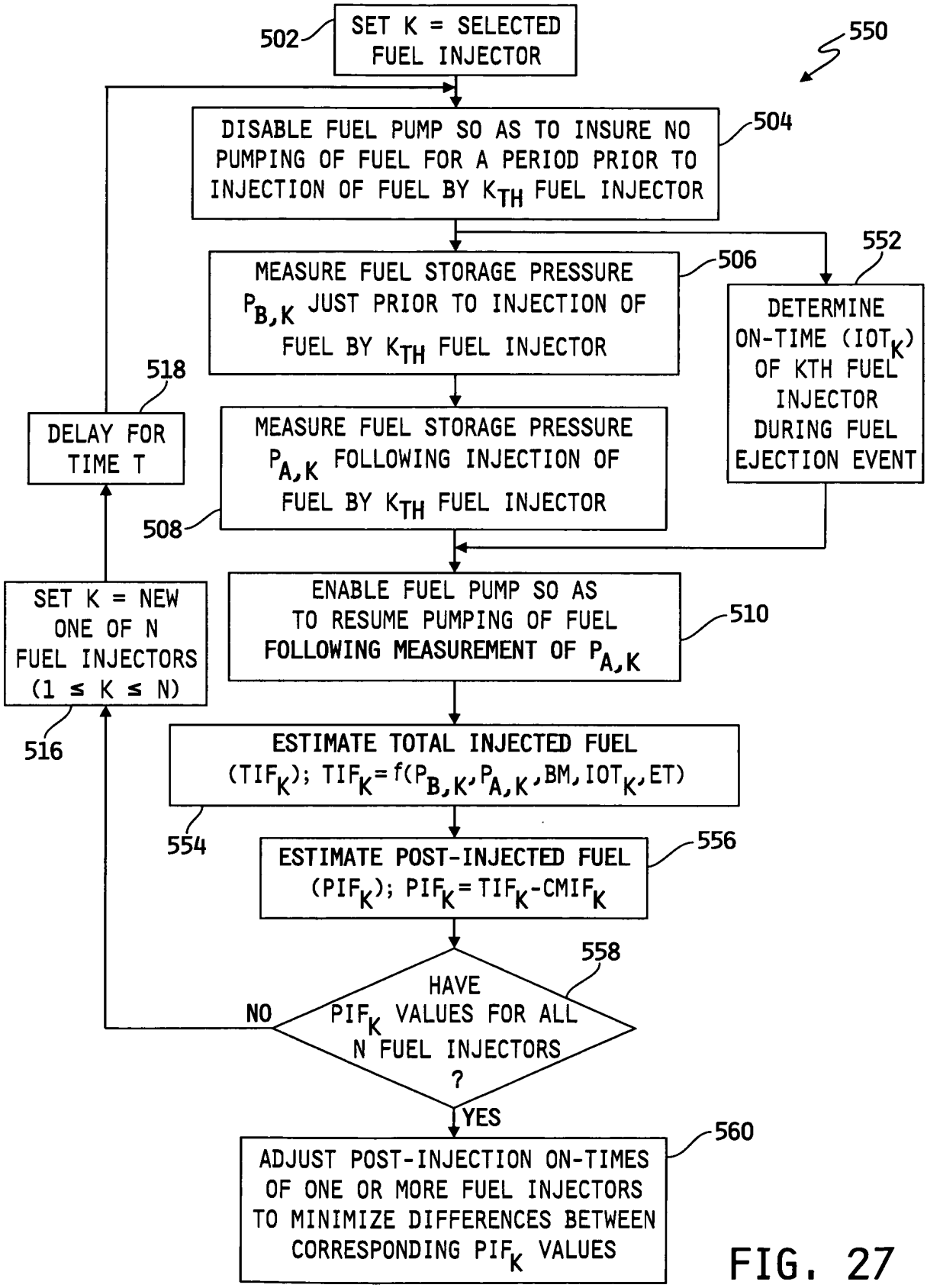
502
SET K = SELECTED FUEL INJECTOR
550
DISABLE FUEL PUMP SO AS TO INSURE NO PUMPING OF FUEL FOR A PERIOD PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
504
MEASURE FUEL STORAGE PRESSURE $P_{B,K}$ JUST PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
506
552
DETERMINE ON-TIME (IOT_K) OF KTH FUEL INJECTOR DURING FUEL EJECTION EVENT
518
DELAY FOR TIME T
MEASURE FUEL STORAGE PRESSURE $P_{A,K}$ FOLLOWING INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
508
SET K = NEW ONE OF N FUEL INJECTORS ($1 \leq K \leq N$)
516
ENABLE FUEL PUMP SO AS TO RESUME PUMPING OF FUEL FOLLOWING MEASUREMENT OF $P_{A,K}$
510
ESTIMATE TOTAL INJECTED FUEL (TIF_K); $TIF_K = f(P_{B,K}, P_{A,K}, BM, IOT_K, ET)$
554
ESTIMATE POST-INJECTED FUEL (PIF_K); $PIF_K = TIF_K - CMIF_K$
556
558
HAVE PIF_K VALUES FOR ALL N FUEL INJECTORS ?
NO
YES
ADJUST POST-INJECTION ON-TIMES OF ONE OR MORE FUEL INJECTORS TO MINIMIZE DIFFERENCES BETWEEN CORRESPONDING PIF_K VALUES
560

FIG. 27

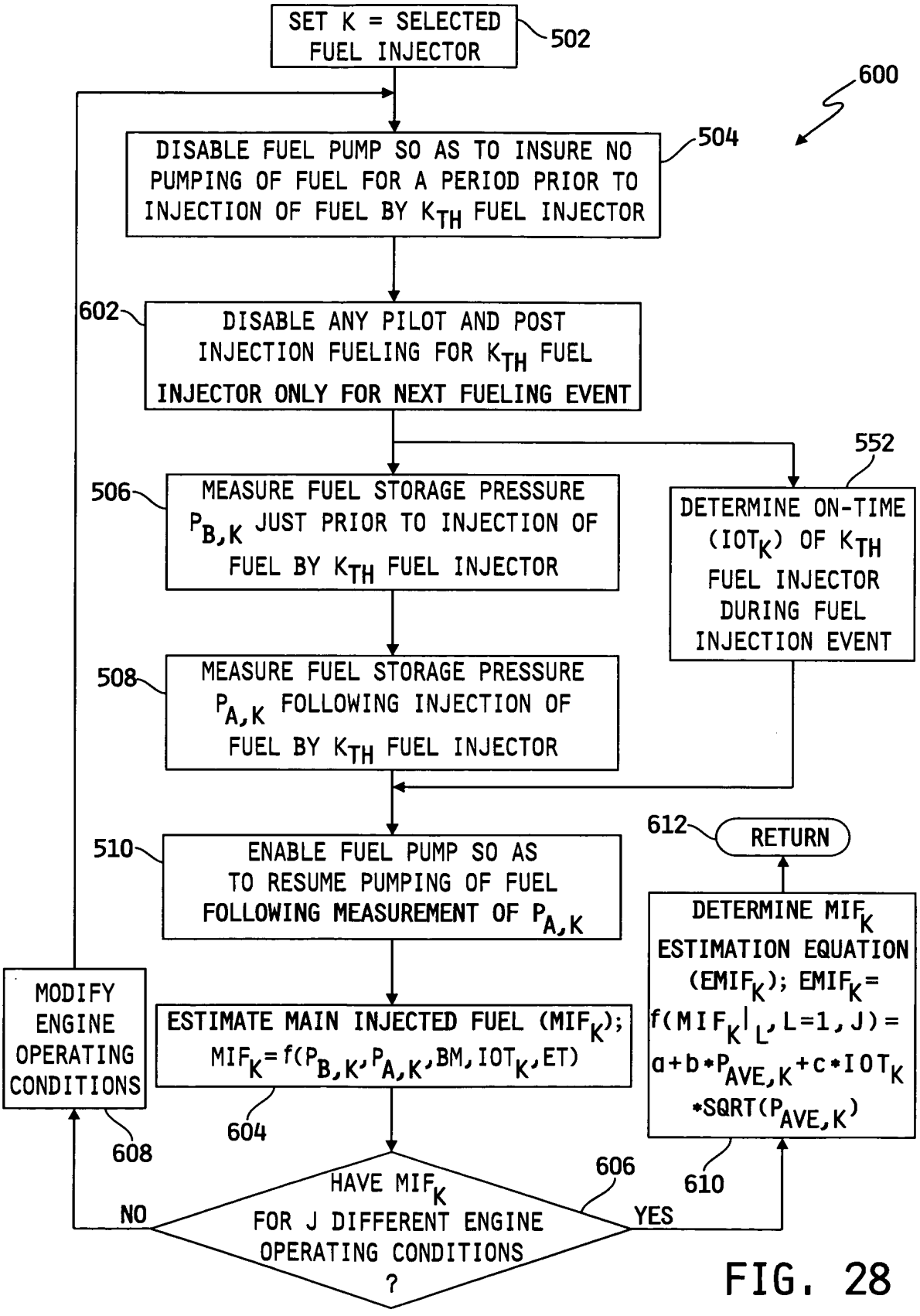
SET K = SELECTED FUEL INJECTOR
502
600
DISABLE FUEL PUMP SO AS TO INSURE NO PUMPING OF FUEL FOR A PERIOD PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
504
602
DISABLE ANY PILOT AND POST INJECTION FUELING FOR K_{TH} FUEL INJECTOR ONLY FOR NEXT FUELING EVENT
552
506
MEASURE FUEL STORAGE PRESSURE $P_{B,K}$ JUST PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
DETERMINE ON-TIME (IOT_K) OF K_{TH} FUEL INJECTOR DURING FUEL INJECTION EVENT
508
MEASURE FUEL STORAGE PRESSURE $P_{A,K}$ FOLLOWING INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
612
RETURN
510
ENABLE FUEL PUMP SO AS TO RESUME PUMPING OF FUEL FOLLOWING MEASUREMENT OF $P_{A,K}$
DETERMINE MIF_K ESTIMATION EQUATION ($EMIF_K$); $EMIF_K = f(MIF_K|_L, L=1,J) = a+b*P_{AVE,K}+c*IOT_K*SQRT(P_{AVE,K})$
MODIFY ENGINE OPERATING CONDITIONS
ESTIMATE MAIN INJECTED FUEL (MIF_K); $MIF_K = f(P_{B,K}, P_{A,K}, BM, IOT_K, ET)$
608
604
606
610
HAVE MIF_K FOR J DIFFERENT ENGINE OPERATING CONDITIONS ?
NO
YES

FIG. 28

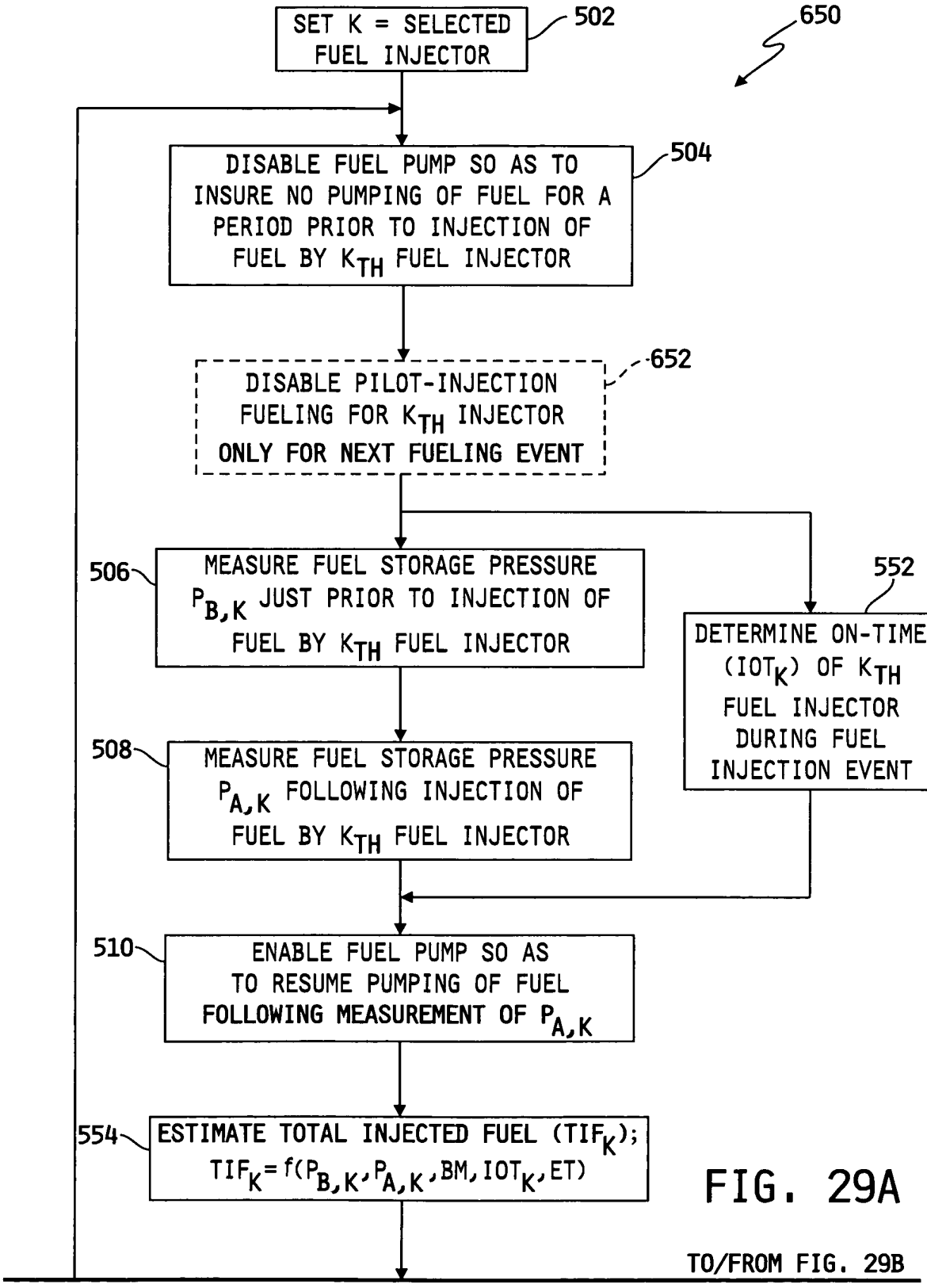
SET K = SELECTED FUEL INJECTOR
502
650
DISABLE FUEL PUMP SO AS TO INSURE NO PUMPING OF FUEL FOR A PERIOD PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
504
DISABLE PILOT-INJECTION FUELING FOR K_{TH} INJECTOR ONLY FOR NEXT FUELING EVENT
652
MEASURE FUEL STORAGE PRESSURE $P_{B,K}$ JUST PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
506
MEASURE FUEL STORAGE PRESSURE $P_{A,K}$ FOLLOWING INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
508
DETERMINE ON-TIME (IOT_K) OF K_{TH} FUEL INJECTOR DURING FUEL INJECTION EVENT
552
ENABLE FUEL PUMP SO AS TO RESUME PUMPING OF FUEL FOLLOWING MEASUREMENT OF $P_{A,K}$
510
ESTIMATE TOTAL INJECTED FUEL (TIF_K); $TIF_K = f(P_{B,K}, P_{A,K}, BM, IOT_K, ET)$
554
TO/FROM FIG. 29B

FIG. 29A

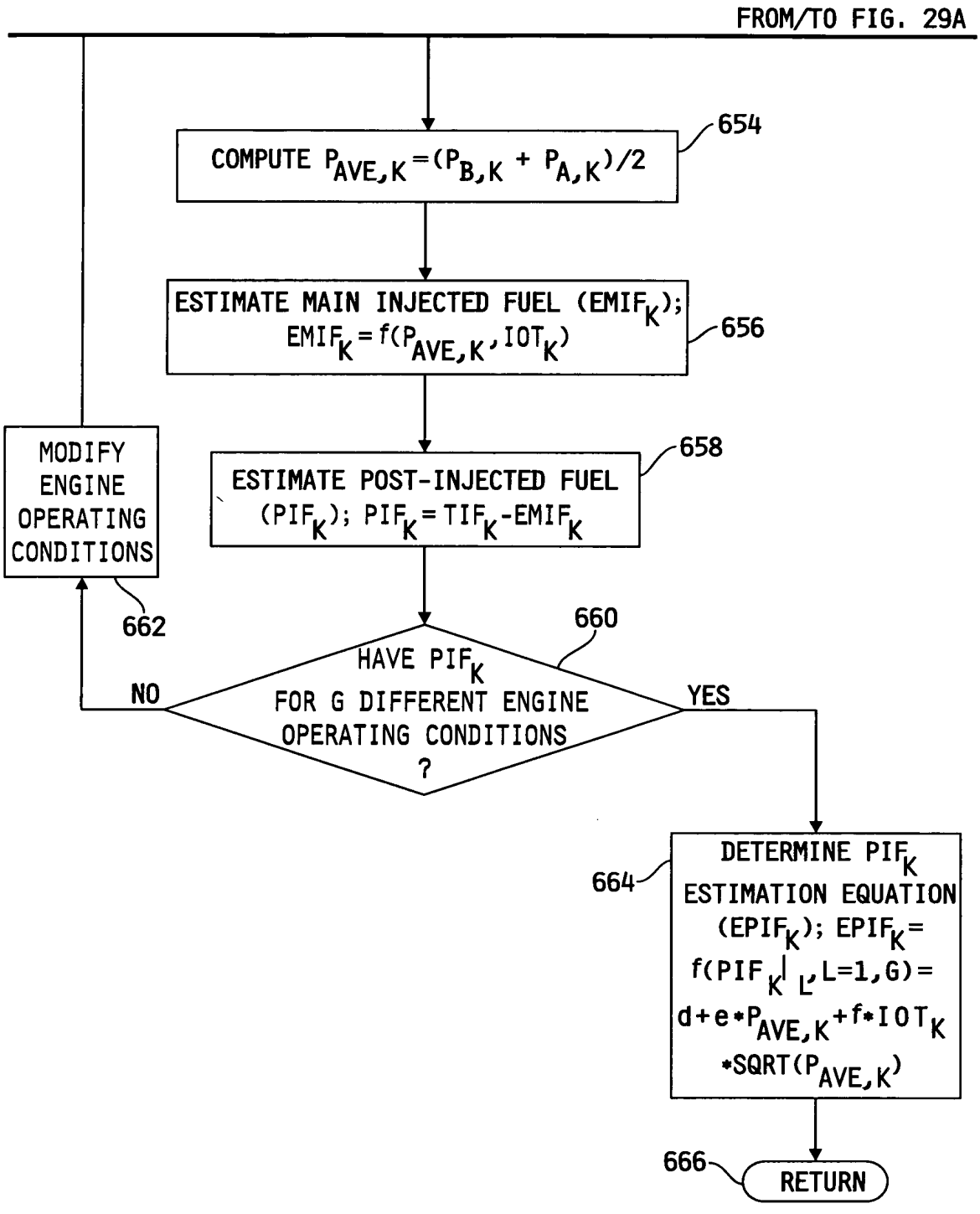
FROM/TO FIG. 29A
COMPUTE $P_{AVE,K}=(P_{B,K}+P_{A,K})/2$
654
ESTIMATE MAIN INJECTED FUEL ($EMIF_K$); $EMIF_K=f(P_{AVE,K}, IOT_K)$
656
ESTIMATE POST-INJECTED FUEL (PIF_K); $PIF_K=TIF_K-EMIF_K$
658
HAVE PIF_K FOR G DIFFERENT ENGINE OPERATING CONDITIONS ?
660
NO
YES
MODIFY ENGINE OPERATING CONDITIONS
662
DETERMINE PIF_K ESTIMATION EQUATION ($EPIF_K$); $EPIF_K=f(PIF_{K|L}, L=1,G)=d+e*P_{AVE,K}+f*IOT_K*SQRT(P_{AVE,K})$
664
RETURN
666

FIG. 29B

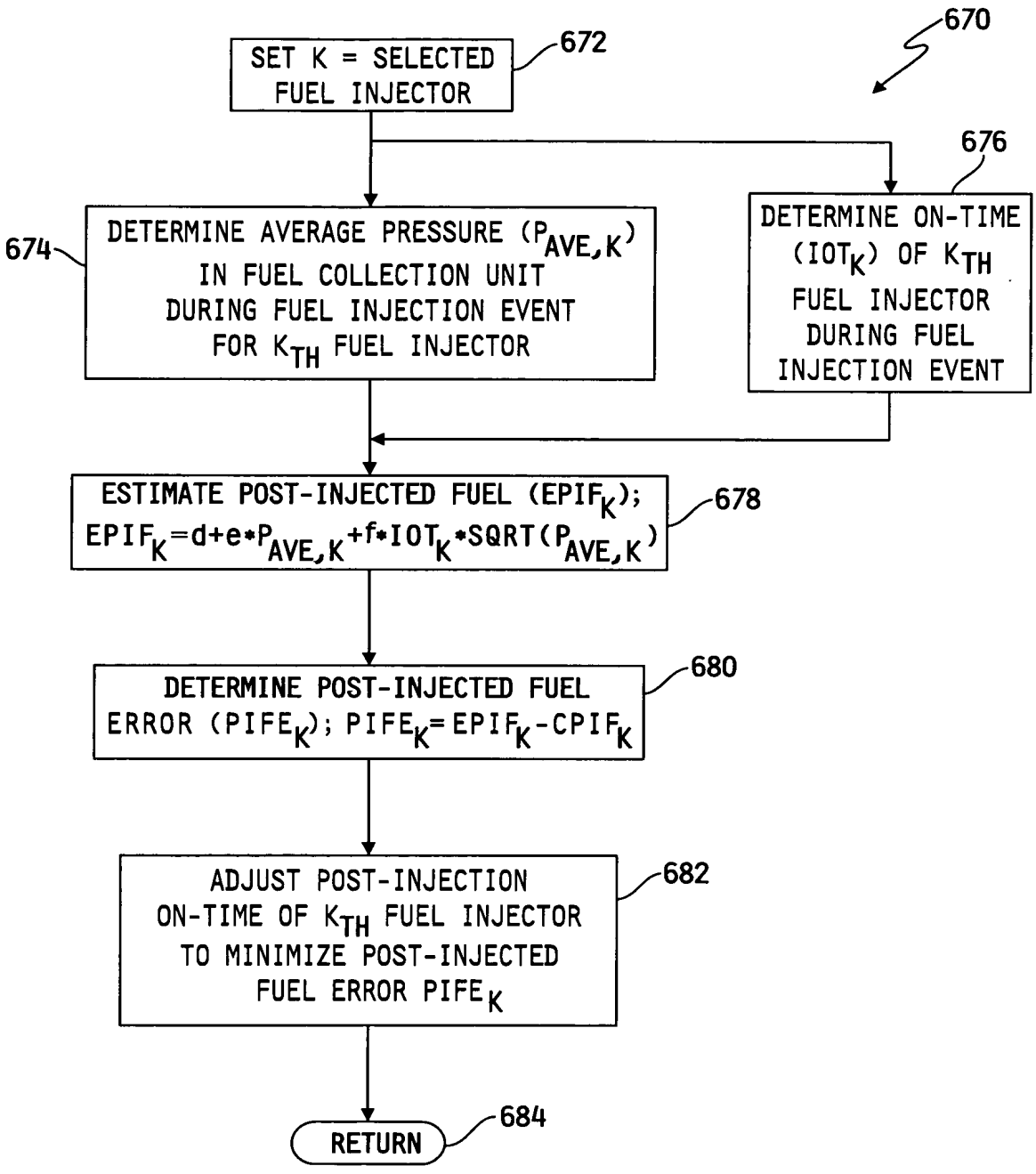
670
SET K = SELECTED FUEL INJECTOR
672
676
DETERMINE AVERAGE PRESSURE ($P_{AVE,K}$) IN FUEL COLLECTION UNIT DURING FUEL INJECTION EVENT FOR K_{TH} FUEL INJECTOR
674
DETERMINE ON-TIME (IOT_K) OF K_{TH} FUEL INJECTOR DURING FUEL INJECTION EVENT
ESTIMATE POST-INJECTED FUEL ($EPIF_K$); $EPIF_K=d+e*P_{AVE,K}+f*IOT_K*SQRT(P_{AVE,K})$
678
DETERMINE POST-INJECTED FUEL ERROR ($PIFE_K$); $PIFE_K=EPIF_K-CPIF_K$
680
ADJUST POST-INJECTION ON-TIME OF K_{TH} FUEL INJECTOR TO MINIMIZE POST-INJECTED FUEL ERROR $PIFE_K$
682
RETURN
684

FIG.30

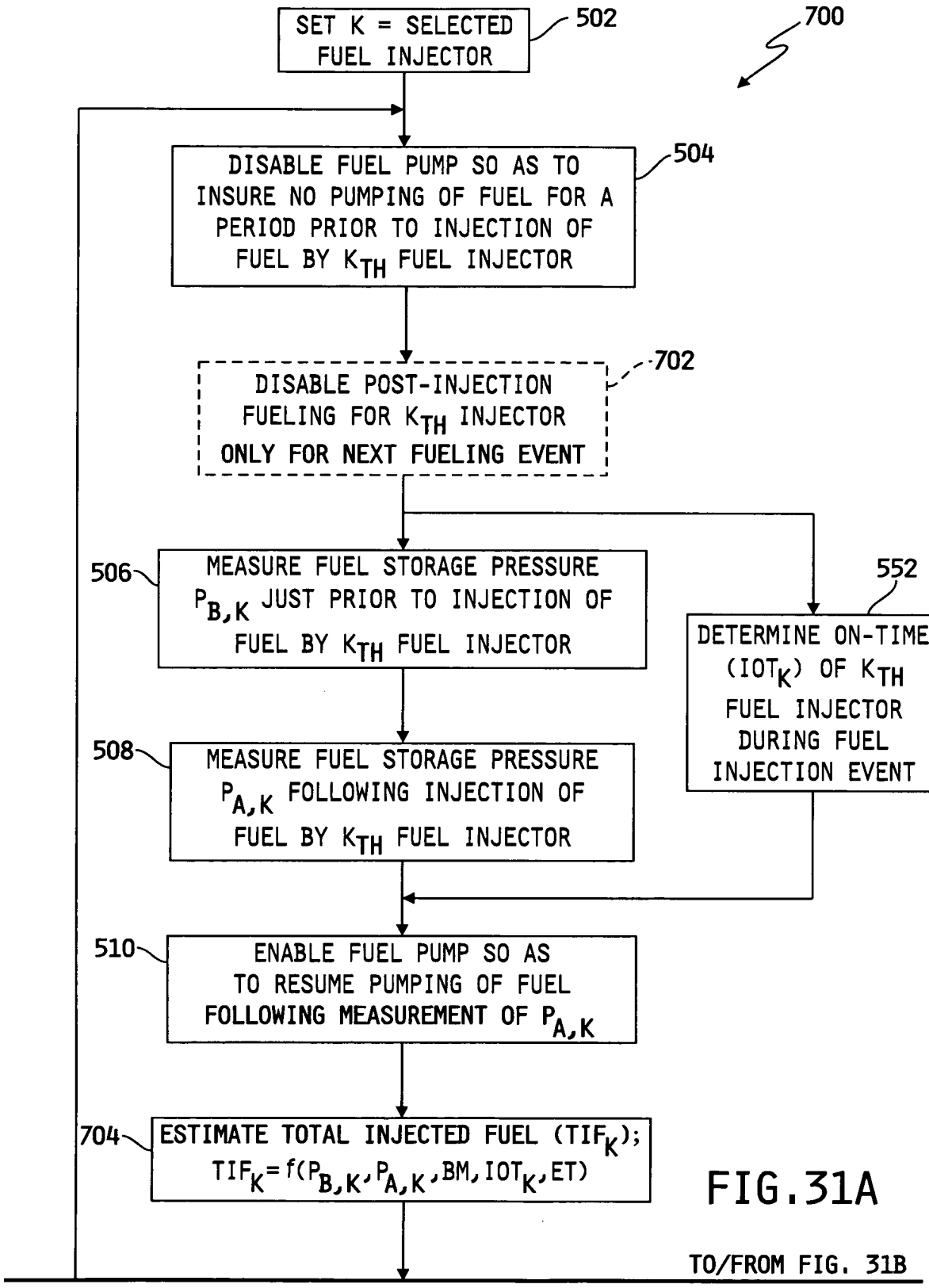
SET K = SELECTED FUEL INJECTOR
502
700
DISABLE FUEL PUMP SO AS TO INSURE NO PUMPING OF FUEL FOR A PERIOD PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
504
DISABLE POST-INJECTION FUELING FOR K_{TH} INJECTOR ONLY FOR NEXT FUELING EVENT
702
MEASURE FUEL STORAGE PRESSURE $P_{B,K}$ JUST PRIOR TO INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
506
DETERMINE ON-TIME (IOT_K) OF K_{TH} FUEL INJECTOR DURING FUEL INJECTION EVENT
552
MEASURE FUEL STORAGE PRESSURE $P_{A,K}$ FOLLOWING INJECTION OF FUEL BY K_{TH} FUEL INJECTOR
508
ENABLE FUEL PUMP SO AS TO RESUME PUMPING OF FUEL FOLLOWING MEASUREMENT OF $P_{A,K}$
510
ESTIMATE TOTAL INJECTED FUEL (TIF_K); $TIF_K = f(P_{B,K}, P_{A,K}, BM, IOT_K, ET)$
704
TO/FROM FIG. 31B

FIG.31A

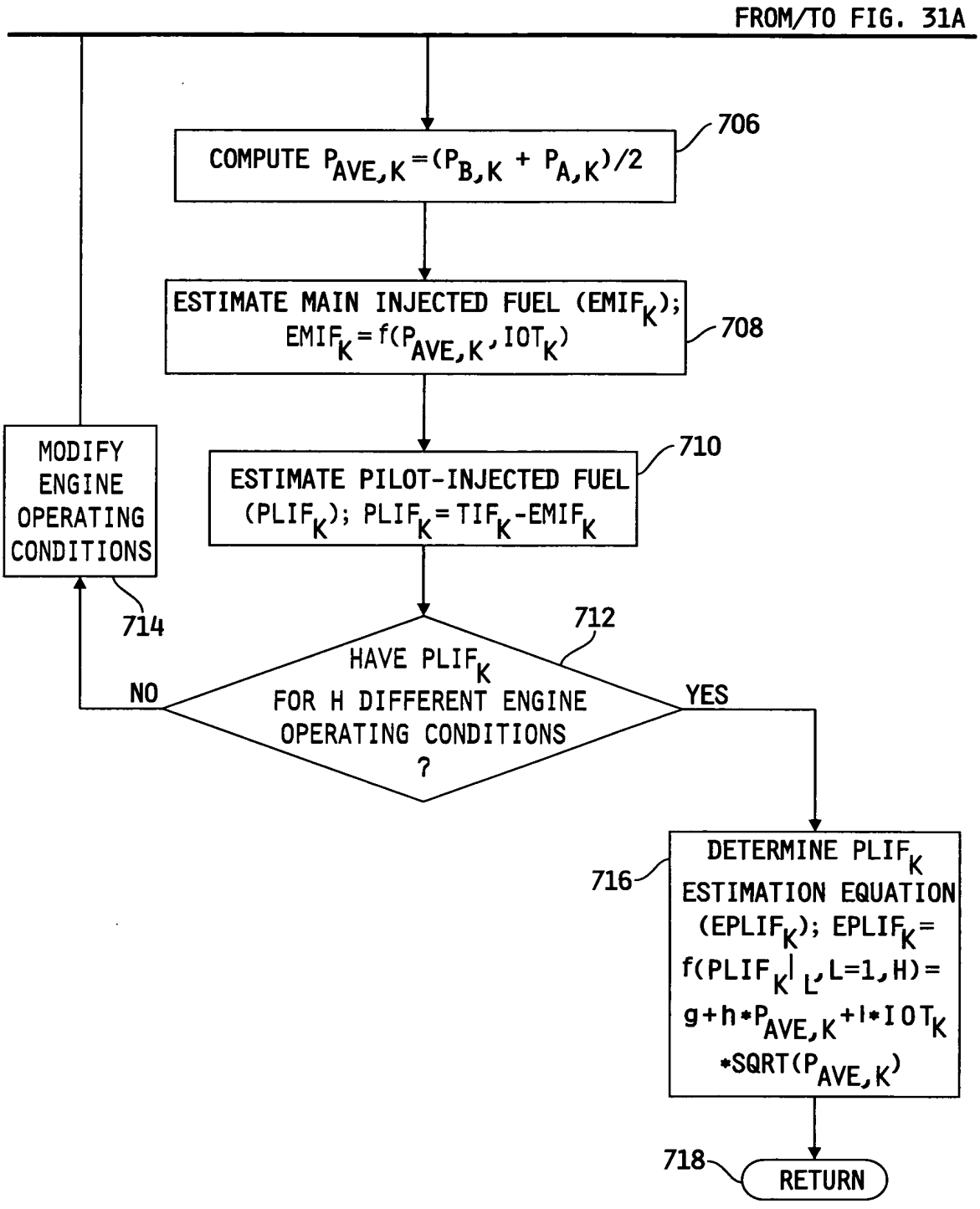
FROM/TO FIG. 31A
COMPUTE $P_{AVE,K}=(P_{B,K}+P_{A,K})/2$
706
ESTIMATE MAIN INJECTED FUEL ($EMIF_K$); $EMIF_K=f(P_{AVE,K}, IOT_K)$
708
ESTIMATE PILOT-INJECTED FUEL ($PLIF_K$); $PLIF_K=TIF_K-EMIF_K$
710
HAVE $PLIF_K$ FOR H DIFFERENT ENGINE OPERATING CONDITIONS ?
712
NO
YES
MODIFY ENGINE OPERATING CONDITIONS
714
DETERMINE $PLIF_K$ ESTIMATION EQUATION ($EPLIF_K$); $EPLIF_K=f(PLIF_K|_L, L=1,H)=g+h*P_{AVE,K}+i*IOT_K*SQRT(P_{AVE,K})$
716
RETURN
718

FIG. 31B

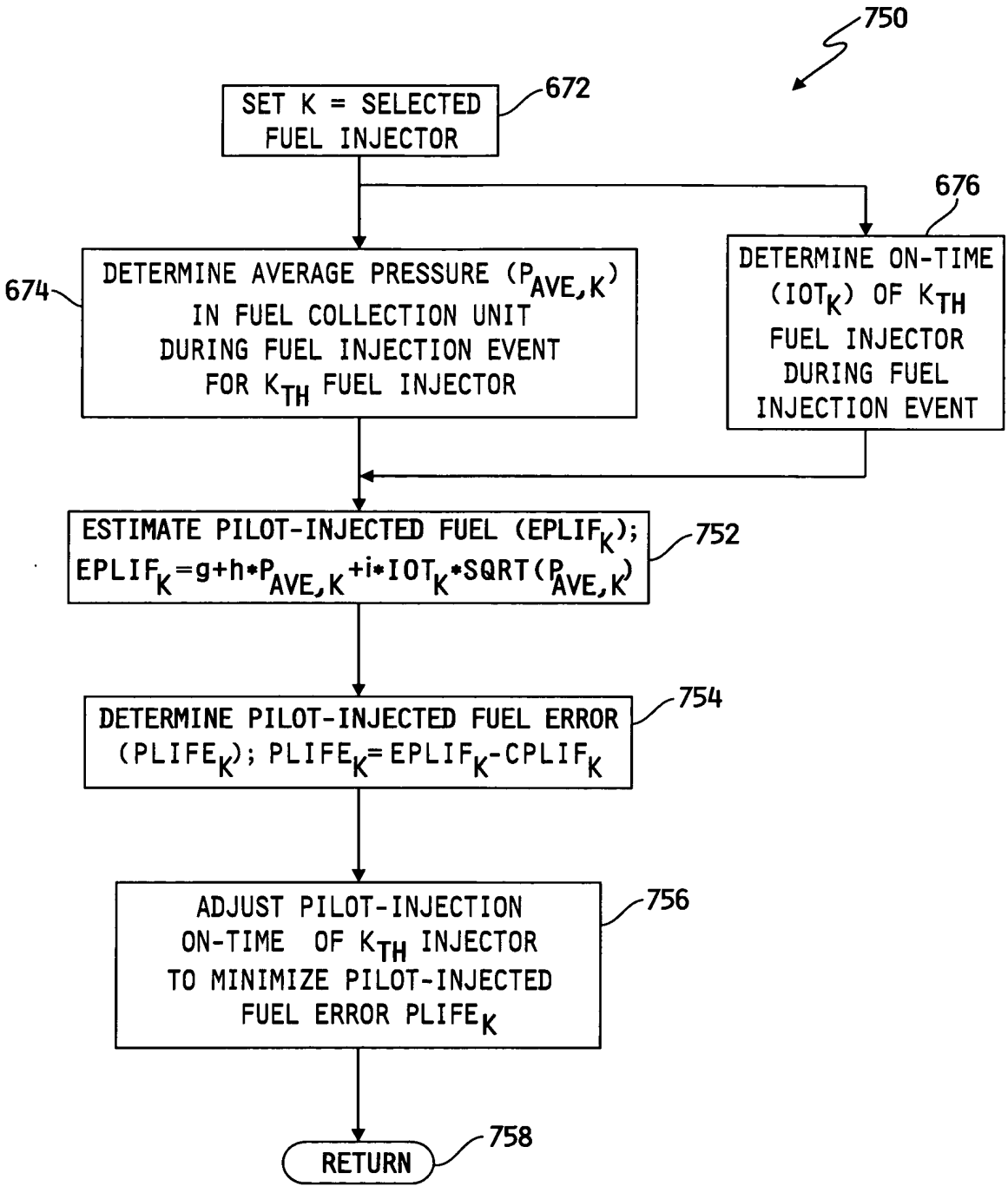
750
SET K = SELECTED FUEL INJECTOR
672
676
DETERMINE AVERAGE PRESSURE ($P_{AVE,K}$) IN FUEL COLLECTION UNIT DURING FUEL INJECTION EVENT FOR K_{TH} FUEL INJECTOR
674
DETERMINE ON-TIME (IOT_K) OF K_{TH} FUEL INJECTOR DURING FUEL INJECTION EVENT
ESTIMATE PILOT-INJECTED FUEL ($EPLIF_K$); $EPLIF_K=g+h*P_{AVE,K}+i*IOT_K*SQRT(P_{AVE,K})$
752
DETERMINE PILOT-INJECTED FUEL ERROR ($PLIFE_K$); $PLIFE_K=EPLIF_K-CPLIF_K$
754
ADJUST PILOT-INJECTION ON-TIME OF K_{TH} INJECTOR TO MINIMIZE PILOT-INJECTED FUEL ERROR $PLIFE_K$
756
RETURN
758

FIG.32

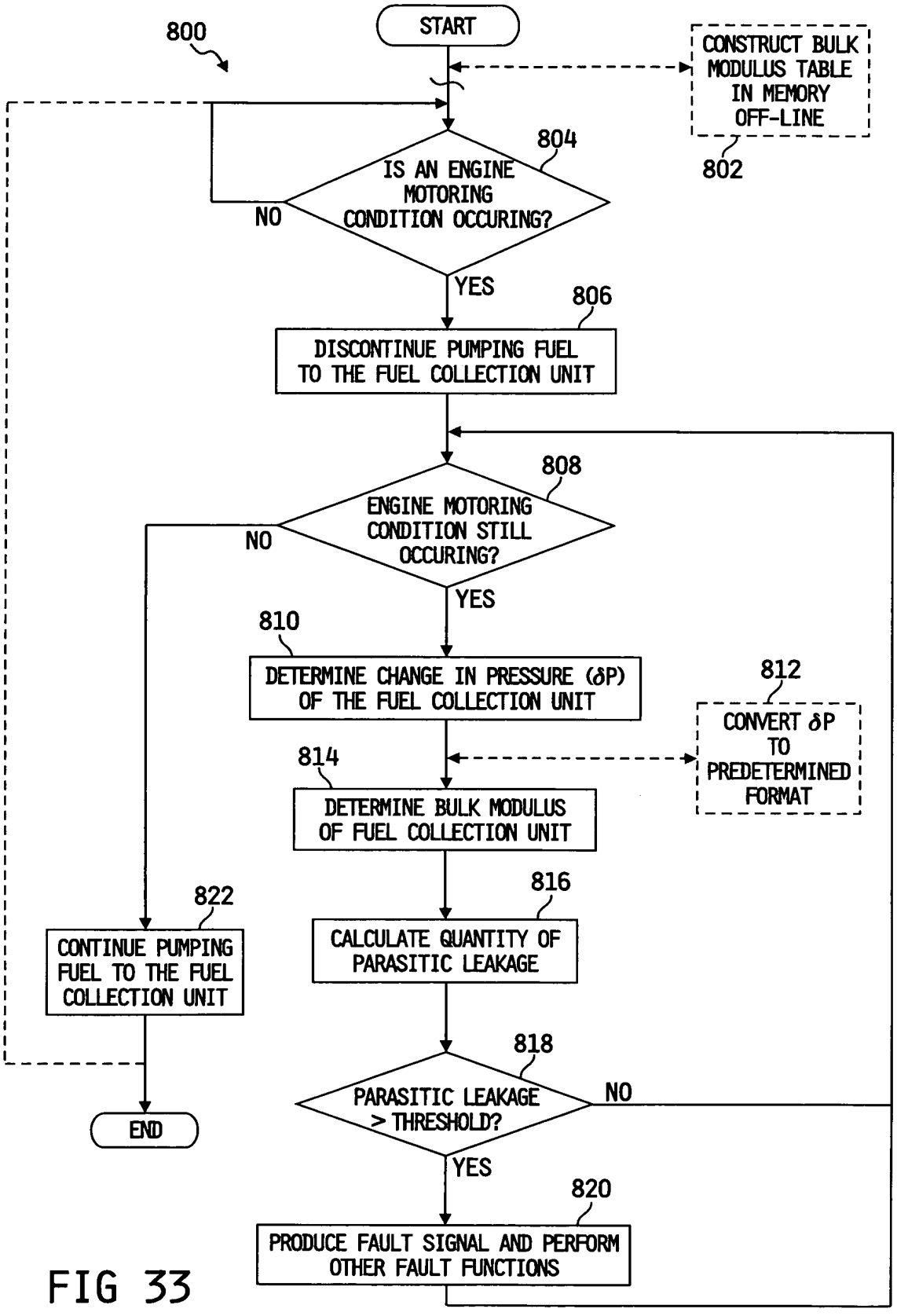
800
START
CONSTRUCT BULK MODULUS TABLE IN MEMORY OFF-LINE
802
804
IS AN ENGINE MOTORING CONDITION OCCURING?
NO
YES
806
DISCONTINUE PUMPING FUEL TO THE FUEL COLLECTION UNIT
808
ENGINE MOTORING CONDITION STILL OCCURING?
NO
YES
810
DETERMINE CHANGE IN PRESSURE (δP) OF THE FUEL COLLECTION UNIT
812
CONVERT δP TO PREDETERMINED FORMAT
814
DETERMINE BULK MODULUS OF FUEL COLLECTION UNIT
816
CALCULATE QUANTITY OF PARASITIC LEAKAGE
818
PARASITIC LEAKAGE > THRESHOLD?
NO
YES
820
PRODUCE FAULT SIGNAL AND PERFORM OTHER FAULT FUNCTIONS
822
CONTINUE PUMPING FUEL TO THE FUEL COLLECTION UNIT
END

FIG 33

	FUEL TEMPERATURE VALUE 1	FUEL TEMPERATURE VALUE 2	• • •	FUEL TEMPERATURE VALUE n
FUEL PRESSURE VALUE 1	β_{11}	β_{12}	• • •	β_{1n}
FUEL PRESSURE VALUE 2	β_{21}	β_{22}	• • •	β_{2n}
FUEL PRESSURE VALUE 3	β_{31}	β_{32}	• • •	β_{3n}
FUEL PRESSURE VALUE 4	β_{41}	β_{42}	• • •	β_{4n}
FUEL PRESSURE VALUE 5	β_{51}	β_{52}	• • •	β_{5n}
	• • •	• • •	• • •	• • •
FUEL PRESSURE VALUE m	β_{m1}	β_{m2}	• • •	β_{mn}

FIG 34